NUCLEONICS

August 1953

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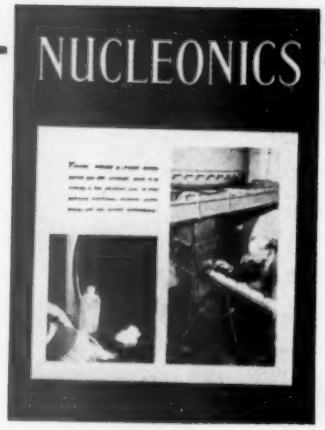

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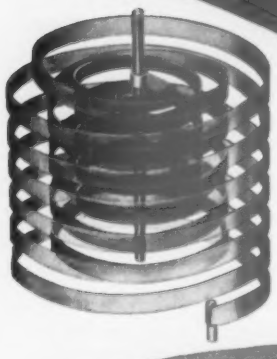

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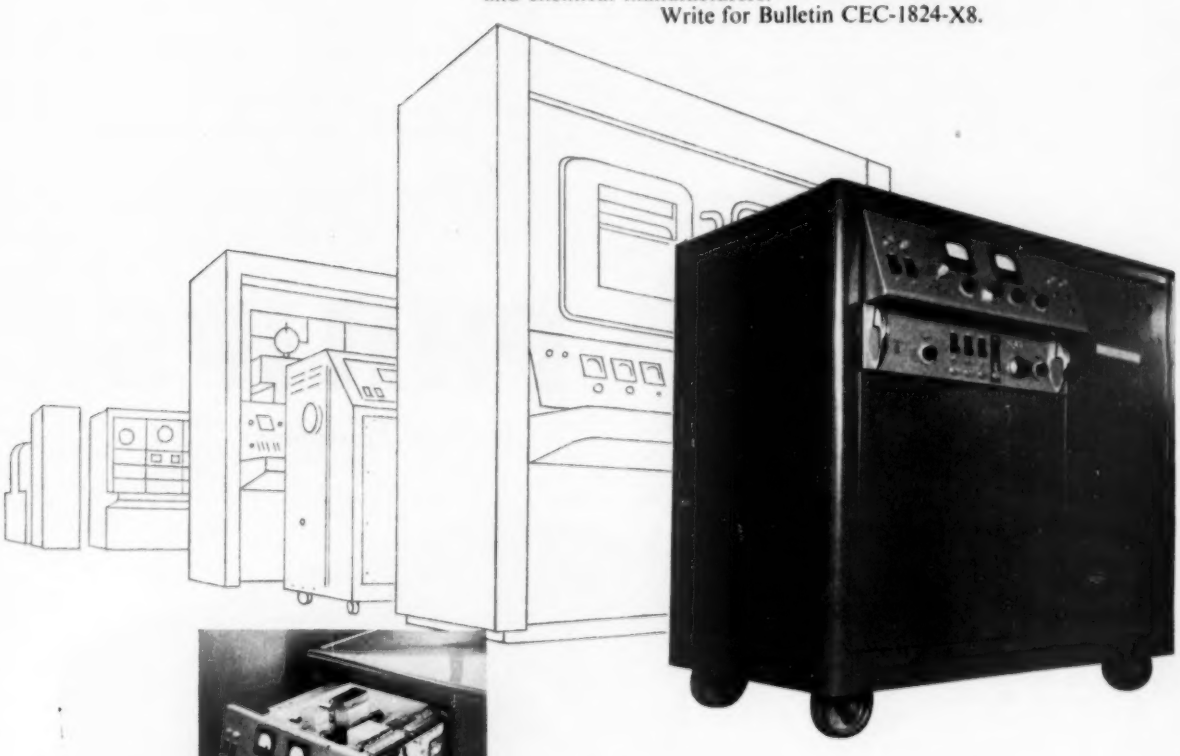

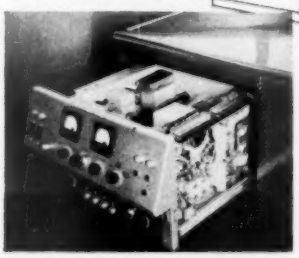

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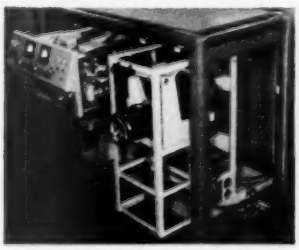

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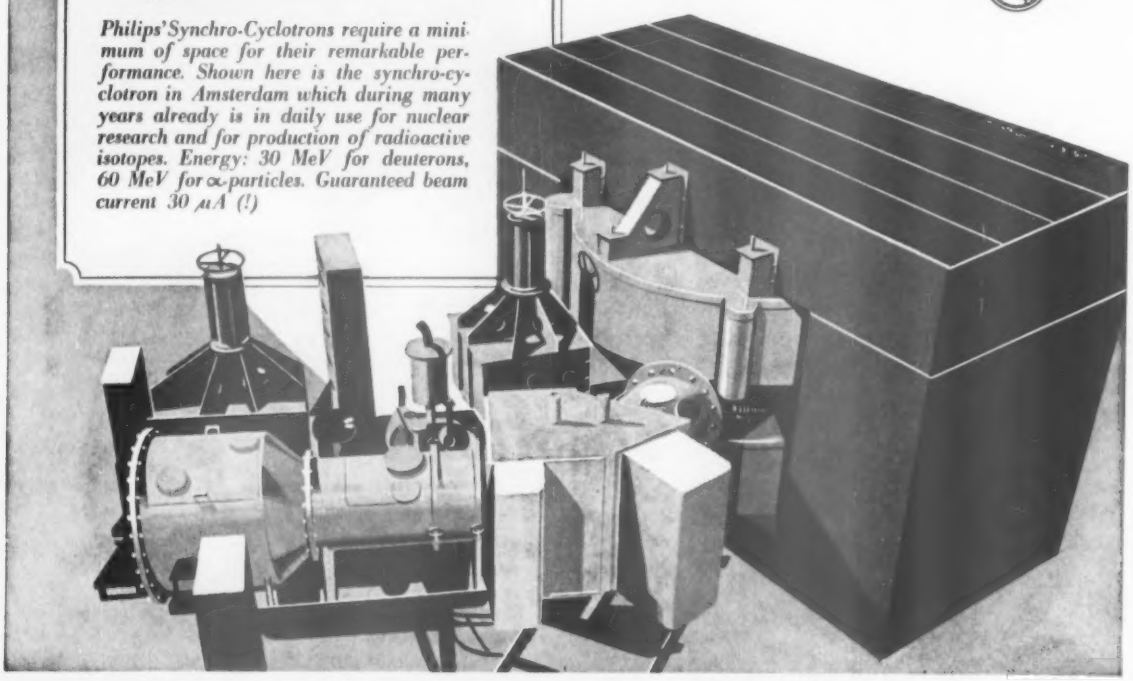

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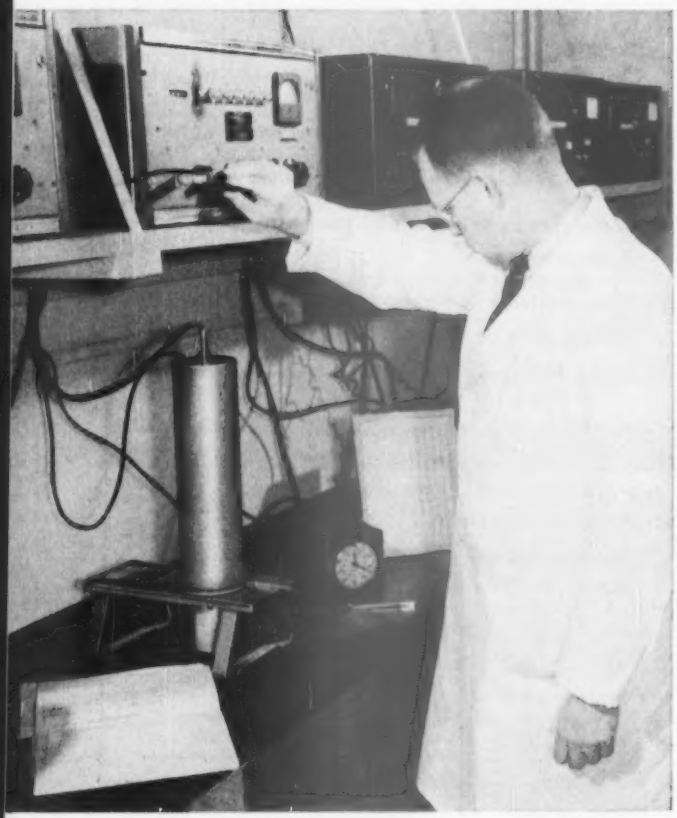

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NUCLEONICS AUGUST, 1953

Jerome D. Luntz, *Editor*

Public Relations for the Peaceful Atom

IT IS SOMEWHAT SURPRISING TO find J. Robert Oppenheimer, Gordon Dean and President Eisenhower all on the same side of the fence on a rather controversial issue with domestic and international implications. But this was the case last month when they all came out very strongly in favor of more candor with the public on atomic weapons data. An informed public, they concluded, is necessary for intelligent support of decisions on vital matters.

Such strong opinions on *military* atomic energy emphasize the need for candor on the *peaceful* atom. If it can be done on the military side, it can and certainly should be done on the peaceful side.

Atomic energy was born amid a variety of emotions—fear, optimism, pessimism, etc. Unfortunately, this emotionalism has clouded discussion of the utilization of atomic energy to the extent that there are all extremes of attitudes on the subject. Some see only evil from atomic energy; others see only good.

It is this divergence of opinion that must be recognized in any atomic energy public relations program, because such a program should follow a line somewhere between the two extremes.

The future of the atomic energy industry depends upon how successful such an effort is. The industry is in its embryonic state. As with any new industry, public attitudes toward it must be fostered in the proper direction at the outset. This is even more important in this field because of the considerable secrecy that exists. With secrecy, there is a very great potential for false rumors and misconceptions.

What is a good public relations program? First, public relations is the creation and carrying out of policies that will be reflected in favorable public opinion. Underlying any successful public relations program must be public confidence. Public relations without public confidence is like a load-bearing structural beam with a surface of steel and a core of balsa wood—fine on the outside but vulnerable to collapse.

Experience indicates that the primary requisite for public confidence is complete frankness. Cicero once said, "What is true, simple and sincere is most congenial to man's nature."

GROWTH OF THE atomic energy industry depends upon acceptance of atomic energy by three groups: Customers for products in whose manufacture or operation atomic energy is involved, the general public, and employees of firms using atomic energy.

Employee relations is of first importance. Any selling of the benefits of atomic energy must start at home—with employees. If employees are not convinced of the desirability and safety of using radioactivity, their lack of conviction will not be kept secret, and, no matter how good the public relations job done outside the plant, money and effort will be wasted.

Next are relations with the general public, primarily people in communities surrounding plants involved in atomic energy activities. Again, these are noncustomers whose attitudes must be given serious consideration.

Finally, there are the customers, the eventual source of revenue for so-called atomic products, which could be anything from nuclear reactors to radiation-sterilized foods or drugs.

To gain the acceptance of all three groups, a positive dynamic approach should be used rather than the fire-fighting method of trying to recoup after damage has been done.

The principal barrier to acceptance is ignorance. This can only be fought with information—information about nuclear radiation, the fact that its hazards can easily be protected against, the fact that there are many more insidious materials in daily use in industry and by the public.

Gamma-Ray Attenuation

PART I

BASIC PROCESSES

Design of gamma-ray shielding requires detailed knowledge of the attenuation of electromagnetic radiation by matter. This article introduces the problem by describing the basic interaction processes of photons with matter. The concluding part, to be published next month, will present a detailed examination of the penetration of the gamma rays

By U. FANO
Nuclear Physics Section
National Bureau of Standards
Washington, D. C.

ELECTROMAGNETIC RADIATION of high photon energy (high frequency) usually originates from excited atomic nuclei, from excited atoms, or from electrons traversing matter, and is called X-rays or gamma rays. In this article on basic interaction processes (*1*), "gamma rays" means high-energy electromagnetic radiation from any source, even though this term usually refers to radiation from nuclear sources only.

This paper deals primarily with gamma rays having photon energies between 0.1 and 10 Mev. Some information will apply to radiation with energies extending roughly one order of magnitude above or below this range.

Gamma rays traversing matter interact with it through separate "elementary" processes. Present information on elementary processes is generally adequate for shielding applications. Each photon usually experiences a succession of elementary processes. The combined effect of a succession of processes upon the over-all propagation of gamma rays has been under study in recent years; progress in this field is reviewed here.

Kinds of Interaction

There are four kinds of interaction, and each will be denoted by a Roman numeral.

Basic interaction with atomic electrons (I). The electromagnetic field of gamma rays exerts an oscillating electric force on the charge of the atomic electrons within any material, and a (smaller) magnetic torque on their spin. Each electron reacts as an elementary particle endowed with mass and with spin angular momentum, and

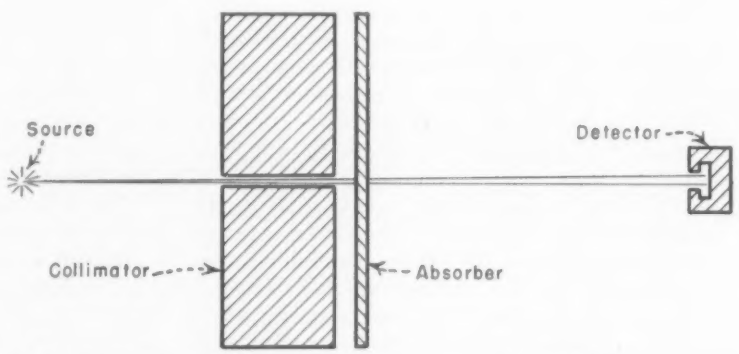

FIG. 1. Arrangement for measuring narrow-beam attenuation coefficient

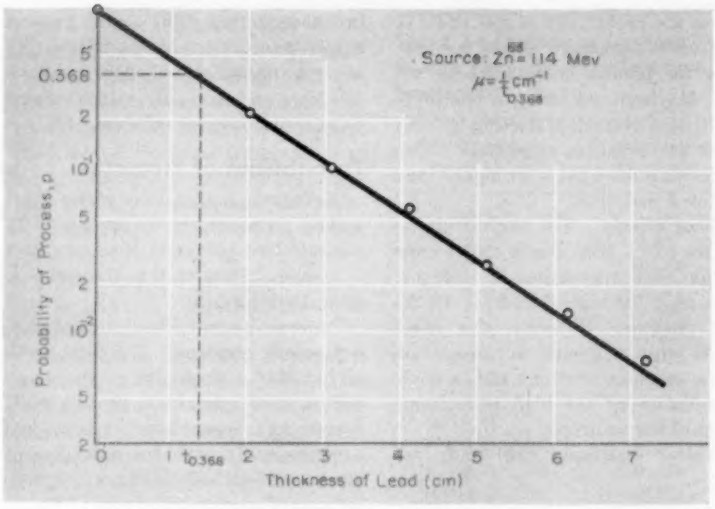

FIG. 2. Experimental verification of narrow-beam attenuation relation and measurement of μ

subject to forces from other constituents of the material.

Basic interaction with nuclear particles (nucleons) (II). The electromagnetic field of gamma rays exerts an oscillating electric force on the charge of the nuclear protons within any material and a (smaller) magnetic torque on the spins of protons and neutrons. Each nucleon reacts as an elementary particle endowed with mass and with spin angular momentum, and subject to forces from other nucleons.

Interaction with electric field surrounding charged particles (nuclei and electrons) (III). The electromagnetic field of gamma rays can induce electric currents in space in which there is also an electrostatic field. These currents are associated with the generation of electron-positron pairs.

Interaction with meson field surrounding nucleons (IV). The electromagnetic field of gamma rays can induce electric currents in the space surrounding a proton or a neutron, in which there is also a meson field. These currents are associated with the generation of mesons.

Effects of Interaction

There are three effects that the interaction may have upon a photon. Effects will be denoted by capital letters.

Outright absorption (A). A photon may disappear as a result of interaction within a material. Its energy is then taken up by the interacting system within the material.

Elastic (coherent) scattering (B). A photon may be deflected (scattered) owing to interaction with an atomic system (such as an atom or nucleus). The possibility of scattering is necessarily associated with, and quantitatively related to, the possibility of absorption. If the atomic system recoils as a whole under the impact of the photon, its internal energy is not increased and the scattering is elastic. The effects of elastic gamma-ray interaction with different parts of the system combine "coherently" (i.e., by addition of amplitudes).

Inelastic (incoherent) scattering (C). If the scattering of a photon causes an atomic particle to recoil with respect to the others, the internal energy of the atomic system is increased, and the photon energy correspondingly depleted. The effects of inelastic gamma-ray interactions with different parts of the system combine "incoherently" (i.e., by addition of the intensities of the effects).

Types of Processes

Different types of processes may arise from each kind of interaction (**I, II, III,** or **IV**) leading to each of the end results (**A, B,** or **C**). Thus there are 12 types of processes in all (*2, 3*). Many of these processes are quite infrequent; some have not yet been observed. The following processes, whose symbol indicates mechanism and end effect, are most important:

Photoelectric effect (IA). A photon disappears and an atomic electron (usually from the proximity of the nucleus) leaves its atom at high speed, having absorbed the photon energy. This effect predominates for lower-energy gamma rays, especially for high-Z materials. Its cross section exceeds 1,000 barns per atom of Pb for 0.1-Mev gammas.

The cross section decreases rapidly with increasing gamma energy, E, very roughly like E^{-3} for $E < 0.5$ Mev, and like E^{-1} for $E > 0.5$ Mev. The cross section for atoms of different elements is roughly proportional to Z^5 for $E \geq 0.1$ Mev.

The ejected electron flies off predominantly sideways to the photon beam for $E \ll 0.5$ Mev. Because of the high photon momentum, the predominant direction is forward for higher energies.

Compton scattering (IC) (*4*). A photon is scattered inelastically and an atomic electron recoils out of an atom, much as though it had been initially free.* The energy taken up by the electron depends primarily on its recoil momentum. This effect predominates for gammas of 1–5 Mev in high-Z materials, and even more greatly and over a much wider energy range in low-Z materials. Its cross section approaches 1 barn per electron for 0.05-Mev gammas and decreases to less than 0.1 barn at 10 Mev.

The recoil electron flies off predominantly in the direction of the incident photon, the more nearly so the higher the fraction of photon energy it carries away and the higher the photon energy. It never recoils backwards, of course.

Pair production (IIIA). A photon of more than 1 Mev disappears and its energy transfers to an electron-positron pair, which springs out of the space around an atomic nucleus or (less frequently) around an atomic electron. This effect predominates for high photon energies, especially in high-Z materials. The cross section is zero at 1 Mev but rises monotonically above this energy until it levels off near 50 Mev for high-Z materials, and at a higher energy for low-Z. The largest cross sections approach 100 barns per atom. In the region where the cross section is rising, it varies from element

* This scattering is actually classed as elastic as long as one considers the electron as an isolated particle, and inelastic if the electron is considered as a *part* of the whole material.

to element approximately in proportion to Z^2.

The electron and positron are projected predominantly in the direction of the incident photon, especially when the photon energy, E, and hence its momentum, are very large. Most of the electrons and positrons are confined to directions within 0.5 Mev/E radians from the photon direction.

Rayleigh scattering (IB). Gamma rays scattered by small angles impart only a small recoil, especially when their energy is low. The recoil is then often absorbed by a whole atom or molecule, so that the scattering action of different atomic electrons combines coherently. Coherent combination enhances the probability of this effect so that it prevails greatly at low energies. Even for photon energies above 0.1 Mev, Rayleigh scattering is less probable than Compton scattering by only one or two orders of magnitude. This scattering is more likely for high-Z than for low-Z materials.

Minor effects. The nuclear photoelectric effect (**IIA**) has a small cross section that approaches 1 barn per atom only for high-Z and for 15–20-Mev photons. However, this effect results most frequently in the ejection of one or more neutrons and is made conspicuous by the high penetrating power of the neutrons.

Nuclear scattering (**IIB**) and Delbruck scattering (**IIIB**) are at present barely detectable. Meson effects (**IV**) become appreciable only near or above 150 Mev, and then only with cross sections of the order of millibarns (*5*).

TABLE 1—Mass Absorption Coefficients (cm^2/gm)*

Photon energy (Mev)	*Materials*			
	Water	*Aluminum*	*Iron*	*Lead*
0.1	0.171(0.167)	0.169(0.160)	0.370(0.342)	5.46(5.29)
0.15	0.151(0.149)	0.138(0.133)	0.196(0.182)	1.92(1.84)
0.2	0.137(0.136)	0.122(0.120)	0.146(0.138)	0.942(0.895)
0.3	0.119(0.118)	0.104(0.103)	0.110(0.106)	0.378(0.335)
0.4	0.106(0.106)	0.0927(0.0922)	0.0939(0.0918)	0.220(0.208)
0.5	0.0967(0.0967)	0.0844(0.0840)	0.0840(0.0828)	0.152(0.145)
0.6	0.0894(0.0894)	0.0779(0.0777)	0.0769(0.0761)	0.119(0.114)
0.8	0.0786(0.0786)	0.0683(0.0682)	0.0668(0.0668)	0.0866(0.0837)
1.0	0.0706(0.0706)	0.0614(0.0614)	0.0598(0.0595)	0.0703(0.0683)
1.5	0.0576(0.0576)	0.0500(0.0500)	0.0484(0.0484)	0.0523(0.0514)
2.0	0.0493(0.0493)	0.0431(0.0431)	0.0422(0.0422)	0.0456(0.0451)
3.0	0.0396(0.0396)	0.0353(0.0353)	0.0359(0.0359)	0.0413(0.0410)
4.0	0.0339(0.0339)	0.0310(0.0310)	0.0330(0.0330)	0.0416(0.0416)
5.0	0.0302(0.0302)	0.0284(0.0284)	0.0314(0.0314)	0.0430(0.0430)
6.0	0.0277(0.0277)	0.0266(0.0266)	0.0305(0.0305)	0.0445(0.0445)
8.0	0.0242(0.0242)	0.0243(0.0243)	0.0298(0.0298)	0.0471(0.0471)
10.0	0.0221(0.0221)	0.0232(0.0232)	0.0300(0.0300)	0.0503(0.0503)

* Figures in parentheses are the values if the contribution from Rayleigh scattering is disregarded.

TABLE 2—Fluorescent Yield in the K Series

Element	*Yield*	*Element*	*Yield*
$_{8}O$	0.00	$_{34}Se$	0.60
$_{10}Ne$	0.01	$_{35}Br$	0.63
$_{12}Mg$	0.02	$_{38}Sr$	0.71
$_{14}Si$	0.05	$_{42}Mo$	0.77
$_{16}S$	0.09	$_{47}Ag$	0.83
$_{17}Cl$	0.11	$_{50}Sn$	0.85
$_{18}A$	0.13	$_{54}Xe$	0.87
$_{20}Ca$	0.17	$_{60}Nd$	0.89
$_{24}Cr$	0.27	$_{70}Yb$	0.92
$_{26}Fe$	0.34	$_{78}Pt$	0.94
$_{28}Ni$	0.42	$_{80}Hg$	0.95
$_{29}Cu$	0.46	$_{82}Pb$	0.95
$_{30}Zn$	0.49	$_{84}Po$	0.96

Probabilities of Processes

To find the probabilities of the interaction processes, it is necessary to measure the absorption of gamma rays in matter. Data on this absorption is given by White (*6*).

"Narrow-beam" attenuation of monochromatic gammas. The total probability that a photon of given energy suffers some interaction process while traversing a layer of matter is studied experimentally with the arrangement shown schematically in Fig. 1. A well-collimated ("narrow") beam of homogeneous (monochromatic) gamma rays penetrates a layer of matter (absorber) and then reaches a detector. Absorption or appreciable deflection of a photon prevents it from reaching the detector. The attenuation of the intensity received by the detector, as the absorber thickness increases, measures the combined probabilities of outright absorption and of deflection.

Exponential law of attenuation. If a photon has a probability p of traversing an absorber of thickness x without suffering absorption or deflection, the probability of no process occurring through a thickness $2x$ must be p^2. This condition implies that p depends on x according to

$$p = e^{-\mu x} \qquad (1)$$

where μ represents the "absorption coefficient" (probability of a process per unit thickness). If x is expressed in centimeters, μ is expressed in cm^{-1}. "Narrow beam" attenuation experiments verify Eq. 1 and measure μ. This is shown in Fig. 2, drawn from the data of Davisson and Evans (*7*).

Components of the absorption coefficient. The total probability, μ, that any process takes place per unit thickness of absorber is the sum of the probabilities of occurrence of the various kinds of processes. "Narrow-beam" experiments yield only the total μ, but the μ's for the various processes are generally provided by the theory or by special experiments. The formula

$$\mu = \mu_{ph} + \mu_{sc} + \mu_{pair} \qquad (2)$$

is often encountered, where μ_{ph} pertains to process **IA**, μ_{sc} to **IC** and **IB**

combined (or to **IC** alone), μ_{pair} to **IIIA**, and the other processes are disregarded.

Mass absorption coefficient. A layer of matter absorbs according to the quantity of matter it contains, which is the thickness traversed (x in Eq. 1) times the density of the material. Therefore, absorber thicknesses are conveniently expressed on a mass basis, in gm/cm². Accordingly, μ is often expressed in $(gm/cm^2)^{-1} = cm^2/gm$ and called the mass absorption coefficient.

Combination of mass absorption coefficients. The probabilities that a photon suffers an interaction process with atoms of different elements in an absorber add up without mutual disturbance.* Therefore, the mass absorption coefficient of a chemical compound or mixture is an average of the mass absorption coefficients of the constituent elements, weighted in proportion to the abundance of each element *by weight*. For example, for water (1 part H, 8 parts O), we have

$$\mu_{H_2O} = (1/9)\,\mu_H + (8/9)\,\mu_O \qquad (3)$$

provided the μ's are expressed as *mass* absorption coefficients.

Half-value layer. The absorber thickness, $t_{1/2}$, which has a probability $1/2$ of letting through a photon undisturbed (i.e., which reduces the intensity of a "narrow beam" to $1/2$) is called the half-value layer of the given absorber material for the given energy of monochromatic gammas. It follows from Eq. 1 that

$$t_{1/2} = (\ln 2)/\mu = 0.693/\mu \qquad (4)$$

since $e^{-\mu t_{1/2}} = 1/2$.

Tables of mass absorption coefficients. Data for certain important substances are given in Table 1 (*6*). The same data diminished by the contribution of Rayleigh scattering (process **IB**) are given in parentheses in Table 1 for convenience in applications where the small-angle Rayleigh process is disregarded. More complete data is given by White (*6*).

As a guide for estimating the Rayleigh-process deflections, one may consider that 60–70% of them fall below

Rayleigh Scattering Angle (degrees)

Energy (Mev)	*0.1*	*1*	*10*
Al	15	2	0.5
Fe	20	3	0.8
Pb	30	4	1

TABLE 3—Fraction of Incident Photon Energy Retained After Compton Scattering

Initial photon energy (Mev)	*Fraction retained by photon*
0.1	0.861
0.15	0.817
0.2	0.782
0.3	0.729
0.4	0.690
0.5	0.659
0.6	0.632
0.8	0.592
1.0	0.560
1.5	0.505
2.0	0.469
3.0	0.423
4.0	0.394
5.0	0.373
6.0	0.357
8.0	0.333
10.0	0.316

TABLE 4—"Relative Range" of Equal-Energy Electrons and Photons in Water

Energy (Mev)	*μR*
0.1	0.004
1.0	0.04
10.0	0.2
100.0	0.6

the amounts shown in the table below, for the specified materials and photon energies.

Sidewise Gamma-Ray Escape

The energy of photons that experience an interaction process in a material need not be entirely dissipated very near the point of interaction. The atomic particles to which the energy is transferred may travel some distance (see *Energy Transport*). More important, part of the energy of the incident photons is carried away in various directions by photons of lower energy as a result of processes among which the following are most important:

Fluorescence. When an inner-orbit atomic electron is ejected by photoelectric effect (process **IA**), one of the outer atomic electrons will take its place and thereby become more tightly bound. The excess binding energy may be released in the form of an X-ray photon (fluorescence). The probability of fluorescence (as opposed to ejection of a second electron) (*8*) and the energy of the radiated photon are increasing functions of the atomic number of the material. Table 2 (*9*) lists fluorescent yields in the K series, which is the probability that an atom that has been ionized in the K shell will emit a photon of a frequency in the K series.

Scattering. Scattered photons carry away a fraction of the incident photon energy, in the event of a Compton process (**IC**), or all of it in the event of coherent scattering (**IB**). Data on the average fraction of the incident energy carried away by a Compton-scattered photon, averaged over all angles of scattering, are shown in Table 3.

Annihilation. When a photon disappears as a result of pair production (process **IIIA**), the positron of the pair eventually combines with an atomic electron, releasing 1 Mev or more, of energy, usually in the form of two photons.

Bremsstrahlung. The gamma-ray energy transferred to electrons (or positrons) within a material may be re-radiated in the form of X-rays (bremsstrahlung). For electrons of energy above 10 Mev, and for high-Z, this effect accounts for removal of most of the energy. At lower energies, the average fraction of energy radiated by an electron (or positron) of energy E (Mev) is of the order of

$$Z\,E/1{,}000 \qquad (5)$$

where Z is the atomic number of the material (*10*). For higher energies there are limited data available (*11*).

Energy Transport

Atomic particles provide a mechanism for transport of the gamma-ray energy.

Electrons and positrons. Most of the energy transferred from gamma rays to a material is taken up by electrons (or positrons) and then dissipated along the path of these particles. The distance traveled by electrons (or positrons) is very small compared to the mean free path of gamma rays at energies up to a few Mev, but not at higher energies, as shown in Table 4 (*1*). Furthermore, the path of elec-

* Exception must be made for the effect of chemical binding upon the contribution of valence electrons to Rayleigh scattering and for the coherent combination of Rayleigh scattering by different atoms, which matters only under special circumstances, particularly in crystals.

TABLE 5—Energy Absorption Coefficients (cm^2/gm)*

Energy (Mev)	*Material*			
	Water	*Aluminum*	*Iron*	*Lead*
0.088	0.0252	0.0445	0.312	2.46
0.10	0.0253	0.0371	0.219	2.16
0.125	0.0266	0.0307	0.123	1.55
0.15	0.0278	0.0282	0.0801	1.08
0.175	0.0289	0.0276	0.0595	0.779
0.20	0.0299	0.0275	0.0485	0.586
0.25	0.0312	0.0279	0.0390	0.358
0.30	0.0320	0.0283	0.0340	0.241
0.40	0.0328	0.0287	0.0306	0.136
0.50	0.0330	0.0287	0.0293	0.0901(0.0904)
0.60	0.0329	0.0286	0.0286(0.0287)	0.0684(0.0689)
0.70	0.0326	0.0283	0.0278(0.0280)	0.0560(0.0566)
0.80	0.0321	0.0278	0.0272(0.0274)	0.0477(0.0483)
0.90	0.0316	0.0274	0.0266(0.0268)	0.0424(0.0431)
1.0	0.0310(0.0311)	0.0269(0.0270)	0.0261(0.0264)	0.0384(0.0391)
1.25	0.0296(0.0297)	0.0257(0.0258)	0.0248(0.0252)	0.0317(0.0325)
1.5	0.0283(0.0284)	0.0246(0.0247)	0.0237(0.0241)	0.0280(0.0290)
1.75	0.0271(0.0272)	0.0236(0.0237)	0.0227(0.0232)	0.0260(0.0275)
2.0	0.0260(0.0261)	0.0227(0.0229)	0.0219(0.0224)	0.0248(0.0265)
2.5	0.0241(0.0243)	0.0213(0.0216)	0.0209(0.0215)	0.0238(0.0260)
3.0	0.0227(0.0229)	0.0201(0.0205)	0.0203(0.0210)	0.0238(0.0264)
4.0	0.0204(0.0208)	0.0188(0.0192)	0.0198(0.0208)	0.0253(0.0290)
5.0	0.0189(0.0194)	0.0180(0.0185)	0.0198(0.0211)	0.0272(0.0317)
6.0	0.0178(0.0184)	0.0174(0.0180)	0.0200(0.0214)	0.0287(0.0344)
7.0	0.0170(0.0176)	0.0171(0.0177)	0.0203(0.0219)	0.0298(0.0368)
8.0	0.0163(0.0170)	0.0169(0.0176)	0.0206(0.0225)	0.0309(0.0391)
9.0	0.0158(0.0165)	0.0168(0.0175)	0.0209(0.0232)	0.0319(0.0410)
10.0	0.0154(0.0161)	0.0167(0.0176)	0.0213(0.0238)	0.0328(0.0428)

* Energy absorption coefficients without corrections for bremsstrahlung loss are given in parentheses.

trons and positrons is very tortuous, especially for high-Z and below 10 Mev.

The quantity μR in Table 4 is the product of the narrow-beam absorption of the X-rays, (which may be regarded as the reciprocal of a range) and of the "true" range of electrons (measured along the track).

Neutrons and other particles. Neutron generation absorbs only a small fraction of the incident gamma energy even under optimum conditions, but the ejected neutrons travel quite far. Protons and other charged fragments ejected from nuclei carry a very minor fraction of the total gamma energy and do not travel far.

Energy-Absorption Coefficient

To characterize the fraction of its energy dissipated by a narrow beam of gamma rays in traversing an absorber, the probability of each interaction process must be multiplied by the probable fraction, f, of the photon energy which is actually dissipated in the absorber as a result of the process.

In the event of a photoelectric effect, the value of f discounts the fluorescence radiation; in the event of scattering it discounts the scattered radiation; in the event of pair production it discounts the annihilation radiation; and in all events it discounts the (usually small) bremsstrahlung loss. Accordingly, we define the energy absorption coefficient, μ_{en}, by modifying Eq. 2 to

$$\mu_{en} = f_{ph}\mu_{ph} + f_{sc}\mu_{sc} + f_{pair}\mu_{pair} \quad (6)$$

The values of the fractions, f, can be estimated from theoretical and experimental data.

Data on $f_{sc}\mu_{sc}$ (for Compton processes only, $f_{sc}\mu_{sc}$ being often indicated by σ_a) are often given in the literature. Data on μ_{en} are often based on the assumption $f_{ph} = f_{pair} = 1$; $f_{ph} \sim 1$ for low-Z materials, and the choice of f_{pair} is not critical as long as μ_{pair} is small. More accurate data are given for certain materials in Table 5.

The values of the fractions, f, were estimated by using the relations

$$f_{ph}{}^K = 1 - F_K K_\alpha/h\nu$$

$$f_{sc} = 1 - R_C - 1/h\nu \times \int_0^{T_{max}} P_C(h\nu,T)TG_{br}(T)dT$$

$$f_{pair} = 1 - 2mc^2/h\nu - 1/h\nu \int_0^{h\nu-2mc^2} P_p(h\nu, T^+, T^-) \times \{T^+G_{br}(T^+) + T^-G_{br}(T^-)\}dT^+$$

where F_K = fluorescent yield in K series, K_α = energy of radiation in K-series, R_C = average fraction of incident photon energy retained by photon after Compton scattering (see Table 3), $P_C(h\nu,T)$ = probability that Compton scattering yields recoil electron of energy T, $P_p(h\nu,T^+,T^-)$ = probability that pair production yields positron of energy T^+ and electron of energy T^-, and $G_{br}(T)$ = fraction of electron energy radiated as bremsstrahlen.

Table 5 gives figures both with and without corrections for bremsstrahlung loss. The simple law of combination of absorption coefficients for a mixture of elements, according to Eq. 3, does not hold exactly when the effect of $G_{br}(T)$ is appreciable.

* * *

The figures in Table 1 that do not include the Rayleigh scattering contribution were calculated by G. R. White. Table 3 was prepared by A. T. Nelms. Table 5 was prepared by G. R. White and I. E. Hornstein.

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Effect of

Gamma Radiation on Certain Rubbers and Plastics

Changes produced in mechanical properties of polyethylene, Nylon, Koroseal, Buna-N, neoprene, natural rubber, and Thiokol by long periods of gamma irradiation have been measured. In general, elastic modulus increases, plastic flow decreases

By JOHN W. RYAN
General Engineering Laboratory
General Electric Company
Schenectady, New York

THE INCREASING DEMAND for knowledge of mechanical deterioration processes that occur when engineering materials are exposed to high-level gamma radiation has been given impetus by more recent engineering applications of the Atomic Energy Commission. This article is concerned with the mechanical changes that occurred in some common organic engineering materials after exposure to an average gamma flux of 10^{11} photons/cm^2/sec for a period of six months. The materials tested were subjected to a program designed to determine the mechanical and chemical changes that occurred when the materials were irradiated.

Samples were prepared and sealed in aluminum capsules. The containers were then sent to the Hanford Engineering Works where they were irradiated in the pit used for "cooling off" fuel slugs. Measurements of flux intensities were made with "totem pole" dosimeters over a period of time until an exposure equivalent to a total irradiation of six months at 10^{11} γ/cm^2/sec was obtained. The energies of the irradiating photons varied with the fission-product spectrum.

Figures 1–7 show the changes in the stress-strain curve observed before and after irradiation. Samples were tested according to A.S.T.M. specification D882-46T. Hardness results, as determined with the Durometer "A" scale, are presented in Table 1.

Table 2 presents the results of a modified compression set test. These measurements were made by compressing samples of the materials to be tested between two washers held together by a nut and bolt. The nut was tightened to a torque of 25 inch-pounds with an appropriate torque wrench. After irradiation, the nut was loosened, and the thickness of the sample was measured after a recovery period of ½ hr. These data were compared with controls that had a similar history, except for their irradiation. Compression set was calculated as % compression set $= (t_0 - t)/t_0 \times 100$

STRESS-STRAIN curves for the seven rubber and plastic materials tested . . .

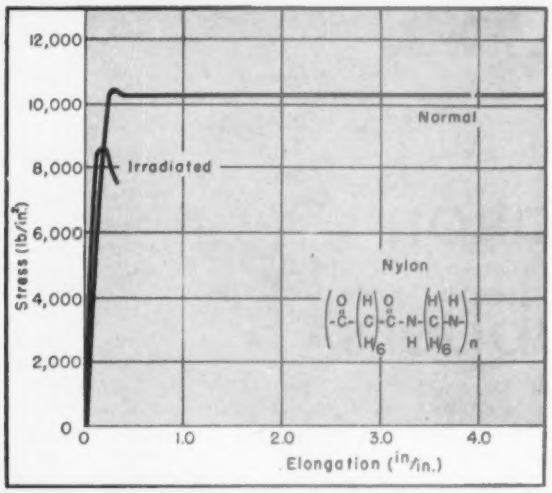

FIG. 1. NYLON; material used was 3003 or 6808, E. I. duPont de Nemours, Inc.

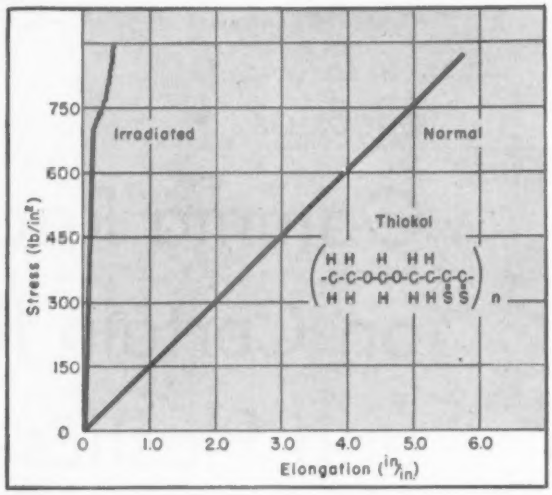

FIG. 2. THIOKOL; material used was PR-1 (70 Durometer), Thiokol

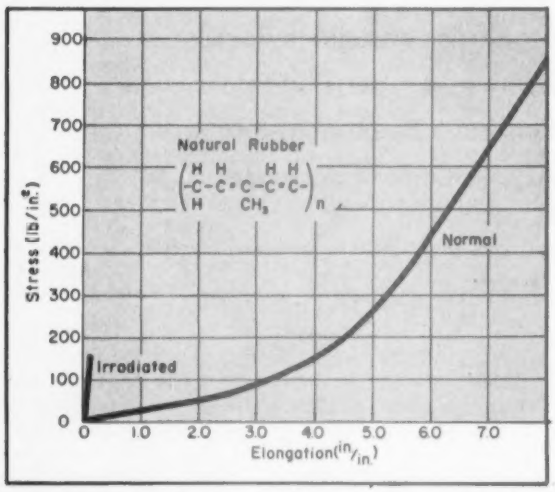

FIG. 5. NATURAL RUBBER; material used was Ceylon style 387, Quaker Rubber Corp.

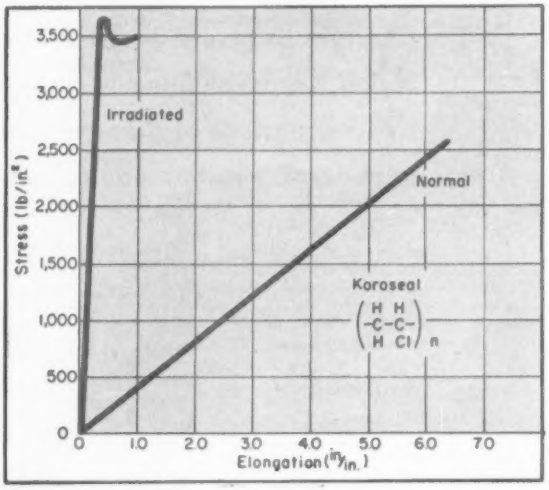

FIG. 6. KOROSEAL; material used was grade 116, Goodrich Rubber Co.

where t_0 = original thickness and t = thickness after treatment.

Visual observations revealed that Koroseal (a polyvinyl chloride polymer) and Neoprene (a chlorinated butadiene polymer) evolved materials that were corrosive to the aluminum containers. A silver nitrate test substantiated the presence of chloride ions.

No observable cracks appeared in any of the materials. In all cases, a loss of flexibility and luster had occurred.

Infrared analysis of the pyrolysis products of Buna-N and Thiokol showed them to be the same as the nonirradiated materials. This suggests that no selective decomposition of any of the groups in the respective monomers had occurred and that the degradation reactions were limited to gas evolution and recombination processes.

Solvent extraction studies on these two materials and subsequent infrared analysis indicated an appreciable increase in the amount of cross linkages. In the case of Buna-N, a selective decomposition of a softener, triethyl phosphate, was observed.

Assuming that the stress-strain curve of linear polymeric material is due to uncoiling of the polymeric chains up to the proportional limit and beyond this point to consist of these extended chains sliding past one another in the plastic flow region until the material fractures,* the change in the stress-elongation curves and increase in hardness may be explained as follows. The deterioration process in the irradiated

* T. Alfrey, "Mechanical Behavior of High Polymers" (Interscience Publishing Co., New York, 1948).

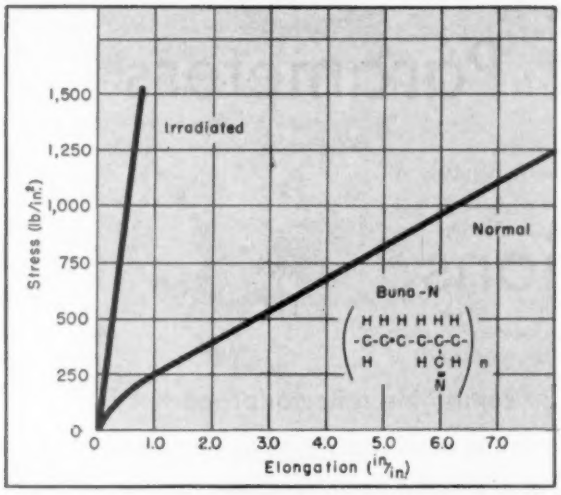

FIG. 3. BUNA-N; material used was supplied by Quaker Rubber Corp.

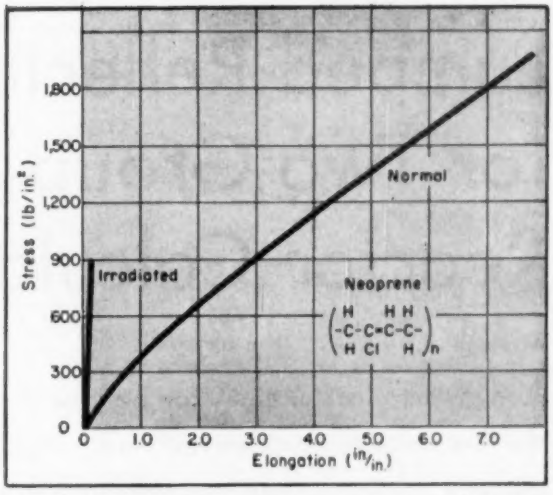

FIG. 4. NEOPRENE; material used was grade M5565 (Fairprene), E. I. duPont de Nemours, Inc.

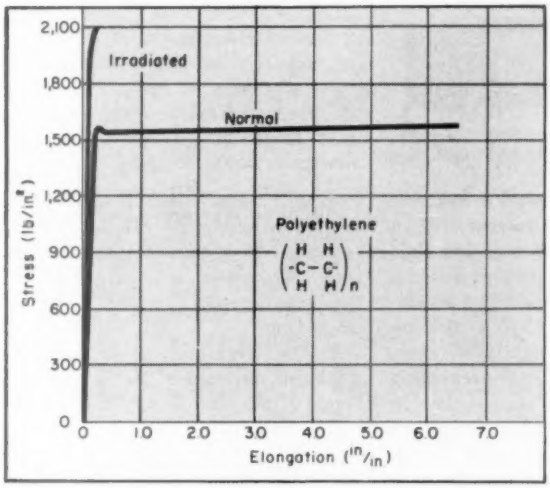

FIG. 7. POLYETHYLENE; material used was supplied by E. I. duPont de Nemours, Inc.

TABLE 1—Hardness of Rubbers and Plastics

Sample	*Control*	*Irradiated*
Polyethylene	100	100
Nylon	100	100
Koroseal	91	100
Buna-N	76	95
Neoprene	83	100
Natural rubber	73	89
Thiokol	71	95

TABLE 2—Compression Set of Materials Tested

Sample	*Control (%)*	*Irradiated (%)*
Buna-N	39	47
Polyethylene	3.5	7
Thiokol	39	44
Koroseal	19	30
Natural rubber	23	36

polymers results in the formation of cross linkages, which hinder the uncoiling and slippage of the linear chains. This results in an increase in the elastic modulus and a decrease of plastic flow in the material as compared to the original material. The loss of flow characteristics would result in an increase in resistance to a penetrometer-type hardness measuring device (such as a Durometer) and therefore result in an increase in hardness.

In general, it has been shown that the mechanical deterioration processes resulted in a decrease of flow characteristics of the materials tested. Gas evolution also occurred, as evidenced by a buildup of pressure in the containers; unfortunately neither quantitative nor qualitative measurements of the gaseous products could be made. It should also be realized that depolymerization and polymerization could contribute to the degradation.

* * *

The author wishes to express his appreciation to E. L. Mincher for preparation of the sample and to D. L. Harms for interpretation of the infrared spectra. The work reported here was done under AEC contract W-31-109 Eng. 52.

THE COVER

Effect of radiation on materials is also being studied at General Electric's Research Laboratory. Tungsten target is removed from million-volt resonant-transformer X-ray apparatus so that electrons can be produced. A few seconds exposure is adequate to change physical characteristics of polyethylene so that it will withstand sterilization at 121° C.

Lumped Reflector Parameters for Two-Group Reactor Calculations

Many reactor calculations can be simplified by combining reflector properties in the three parameters derived here. Application to such problems as comparison of reflector configurations and circuit constants in electrical analogs is shown

By DANIEL FIENO, HAROLD SCHNEIDER, and ROBERT B. SPOONER
National Advisory Committee for Aeronautics
Lewis Flight Propulsion Laboratory
Cleveland, Ohio

THE CLOSE ANALOGY between the physical concepts and equations for the diffusion of neutrons in a reactor and the flow of current in an electric transmission line suggests the application of already developed electrical engineering techniques for handling problems connected with reactor design.

The use of lumped electric circuit elements to approximate a continuous transmission line has been successfully employed to simulate the diffusion of neutrons by electrical analog simulators (*1*). In the analogy, the neutron fluxes and the diffusion currents are simulated, respectively, by the electric potentials and currents of the transmission line.

The analysis and examples given here describe an additional transmission-line concept that can be applied to the one-dimensional solution of the neutron-group equations.

The neutron diffusion, absorption, and moderating properties of the material in a passive reactor zone of finite extent give rise to a particular relation between neutron fluxes and diffusion current at the interface between that medium and an adjacent reactor zone. The diffusion of neutrons into the passive zone can be treated in identical manner to the flow of current into an analogous electric transmission line connected to an unspecified sending circuit. The transmission line is ordinarily characterized by a definite length, terminating impedance, characteristic impedance, and attenuation constant. To specify its reaction on the sending circuit, the line is replaced by an equivalent sending-end impedance that behaves like the line with respect to its reaction on any other electric circuit. The neutron reflector, when described by a similar set of properties, can be treated in the same analytical manner as the transmission line.

In the two-group approximation, the only processes occurring in a passive reactor zone are the reflection of fast and thermal neutrons and the moderation of fast neutrons and their reflection as thermal neutrons. A minimum of three reflector parameters will, therefore, describe the action of the passive zone. The use of transmission-line-like properties gives this set of three parameters and introduces the following advantages:

1. Reflectors or general passive zones with structures based on usual engineering requirements can be directly compared by a consideration of these three parameters in connection with the requirements imposed by the reactor core.

2. The definition of a neutron-diffusion impedance for a reflector region is immediately applicable to the reactor simulator. Here, the reflector network is actually replaced by a single resistor or combined resistor and current source. This leads to great simplification and more rapid operation of the simulator.

3. The effective replacement of a reflector by suitable properties applied at the core-reflector interface suggests the use of these properties in numerical calculations to define new boundary conditions applied only to the neutron flux in the reactor core. This simplified boundary-condition concept for a simply reflected reactor leads to a set of two boundary equations in place of the usual four equations. The 2×2 criticality determinant derived from the boundary equations is, however, of approximately the same complexity as the ordinary criticality determinant reduced in order to a 2×2 determi-

nant. The simplified boundary conditions are especially useful when applied to a multiregion reflector (*2*). There is then no increase in the complexity of the criticality determinant.

Neutron-Diffusion Properties

The definition of characteristic diffusion properties for a neutron-reflector material is based on the neutron-balance equations applied to the reflector region of a reactor segment with its center at the origin of the variable r.

The equation for the fast-neutron group is

$$\omega r^m \frac{\lambda_{tr,f}}{3}\left(\frac{d^2\phi_f}{dr^2}+\frac{m}{r}\frac{d\phi_f}{dr}\right)-\omega r^m \Sigma_{a,f}\phi_f - \omega r^m \frac{\lambda_{tr,f}}{3} B^2\phi_f = 0 \quad (1)$$

where the constant ω determines the size of the reactor segment considered; and $m = 1$, 2, or 0 depending on whether the reactor geometry is cylindrical, spherical, or rectangular, respectively.

The factor ωr^m serves to make Eq. 1 a neutron-conservation equation applicable to the entire reflector segment, and permits a comparison with the analogous electric-transmission-line equation, with a direct numerical equivalence of terms.

The nuclear constants are defined in the list of symbols. The buckling constant, B, applies only to reactor configurations having finite linear dimensions in other than the r-direction.

Equation 1 is similar in form to the equation for the potential on the nonuniform electric transmission line with distributed resistance and leakage shown in Fig. 1.

The line of length $(r_b - r_c)$ has a series resistance per unit length of $R_{0,f}/r^m$ and a shunt conductance per unit length of $r^m G_{0,f}$. A potential ϕ_f is applied at the sending end of the line at r_c. The terminating impedance on the line is zero or infinite for the requirements $\phi_f(r_b) = 0$ or $\partial\phi_f(r_b)/\partial r = 0$, respectively. These requirements correspond, respectively, to those for a finite neutron reflector bounded by a nonreflecting region, or to a perfect reflector or identical image reflector region and source of neutrons.

Equation 1 transforms to the transmission-line equation by the definition of the following quantities

$$R_{0,f} = \frac{3}{\omega\lambda_{tr,f}};\quad G_{0,f} = \omega\Sigma_{a,f} + \frac{\omega\lambda_{tr,f}B^2}{3} \quad (2)$$

The transformed Eq. 1 is then

$$\frac{d^2\phi_f}{dr^2}+\frac{m}{r}\frac{d\phi_f}{dr} - G_{0,f}R_{0,f}\phi_f = 0 \quad (3)$$

Two combinations of the quantities defined in Eq. 2 appear in Eq. 3 and its solution. Therefore, let

$$Z_{0,f}^2 = \frac{R_{0,f}}{G_{0,f}};\quad \alpha_f^2 = R_{0,f}G_{0,f} \quad (4)$$

Because of their transmission-line analogs, these quantities are defined as a fast-neutron characteristic impedance, $Z_{0,f}$, and a fast-neutron attenuation constant, α_f.

The neutron balance equation for the thermal-neutron group transforms into a transmission-line equation

$$\frac{d^2\phi_{th}}{dr^2}+\frac{m}{r}\frac{d\phi_{th}}{dr} - G_{0,th}R_{0,th}\phi_{th} = -R_{0,th}g_{th,f}\phi_f \quad (5)$$

with the definition of thermal parameters corresponding to those given in Eqs. 2 and 4. An additional parameter

$$g_{th,f} = \omega p_{th}\Sigma_{a,f} \quad (6)$$

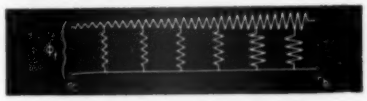

FIG. 1. Transmission line with distributed resistance and leakage

Symbols Used

- B^2 = buckling constant for directions normal to r
- C = undetermined constant
- G_0 = neutron conductance defined by Eq. 2
- $g_{th,f}$ = neutron transconductance defined by Eq. 6
- $I(r)$ = neutron diffusion current at point r
- m = 0, 1, 2
- $P_{th,f}$ = reflection parameter defined by Eq. 13
- p_{th} = neutron resonance escape probability
- R_0 = neutron diffusion resistance defined by Eq. 2
- r = distance variable
- r_b = over-all reactor radius
- r_c = position of core-reflector interface
- Z = reflector impedance
- Z_0 = characteristic impedance of reflector material
- α = attenuation constant of reflector material
- λ_{tr} = neutron transport mean free path
- Σ_a = macroscopic neutron absorption cross section (includes slowing in fast group)
- Φ = general function
- $\phi(r)$ = neutron flux at point r
- ω = reactor-segment size factor
- f = fast-neutron group
- th = thermal-neutron group

gives a thermal-neutron source on the right-hand side of Eq. 5 equivalent to a current introduced per unit length in an electric transmission line.

The general solutions of Eqs. 3 and 5 for the fast- and thermal-neutron fluxes, respectively, are

$$\phi_f(r) = C_f\Phi(\alpha_f r) \quad (7)$$

and

$$\phi_{th}(r) = C_{th}\Phi(\alpha_{th}r) - \frac{g_{th,f}R_{0,th}C_f\Phi(\alpha_f r)}{\alpha_f^2-\alpha_{th}^2} \quad (8)$$

where C_f and C_{th} are constants determined from the known flux at the reflector-core interface r_c, and $\Phi(\alpha_f r)$ and $\Phi(\alpha_{th}r)$ are the homogeneous components of the general solutions of Eqs. 3 and 5, respectively, for the particular geometry and boundary conditions in question. Specific values of $\Phi(\alpha r)$ and $\Phi'(\alpha r)$ are given in Table 1 of reference *2* for various boundary conditions and geometries.

The net fast-neutron diffusion current, $I_f(r)$, in the positive r-direction at any point in the reflector is

$$I_f(r) = \frac{-r^m}{R_{0,f}}\frac{d\phi_f(r)}{dr} = -r^m\frac{C_f}{Z_{0,f}}\Phi'(\alpha_f r) \quad (9)$$

and the net thermal-neutron diffusion current, $I_{th}(r)$, is

$$I_{th}(r) = \frac{-r^m}{R_{0,th}}\frac{d\phi_{th}(r)}{dr} = -r^m\frac{C_{th}}{Z_{0,th}}\Phi'(\alpha_{th}r) + \frac{r^m g_{th,f}C_f\alpha_f\Phi'(\alpha_f r)}{\alpha_f^2-\alpha_{th}^2} \quad (10)$$

where

$$\Phi'(\alpha r) = \frac{d}{d(\alpha r)}\{\Phi(\alpha r)\}$$

The general function $\Phi(\alpha r)$ leads to two reflector-impedance parameters defined by

$$Z_f(r) = -\frac{Z_{0,f}}{r^m}\frac{\Phi(\alpha_f r)}{\Phi'(\alpha_f r)} \quad (11)$$

$$Z_{th}(r) = -\frac{Z_{0,th}}{r^m}\frac{\Phi(\alpha_{th}r)}{\Phi'(\alpha_{th}r)} \quad (12)$$

The fast-neutron diffusion current at the reflector boundary is then given by

$$I_f(r_c) = \phi_f(r_c)/Z_f(r_c)$$

and the thermal current is

$$I_{th}(r_c) = \frac{\phi_{th}(r_c)}{Z_{th}(r_c)} - \frac{P_{th,f}(r_c)}{Z_f(r_c)}\phi_f(r_c)$$

where $P_{th,f}(r_c)$ is a reflection parameter defined by the following expression:

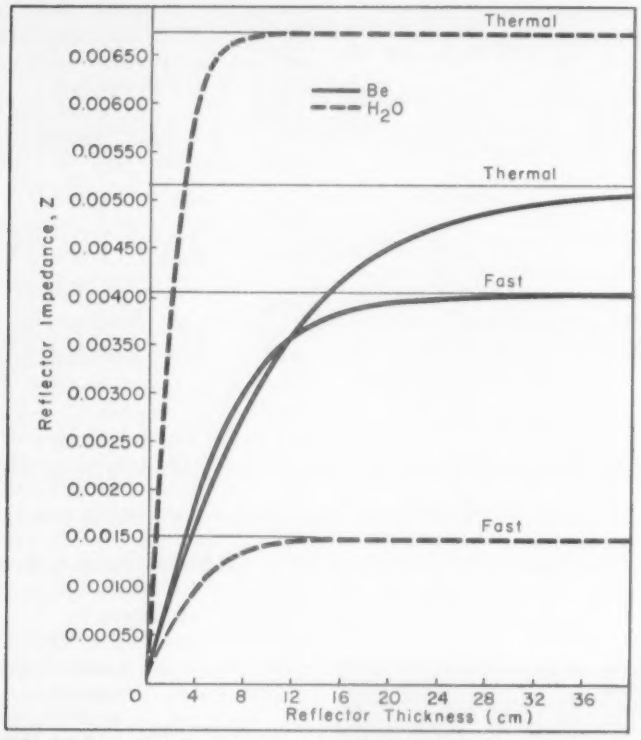

FIG. 2. Fast- and thermal-neutron impedances for beryllium and water reflectors

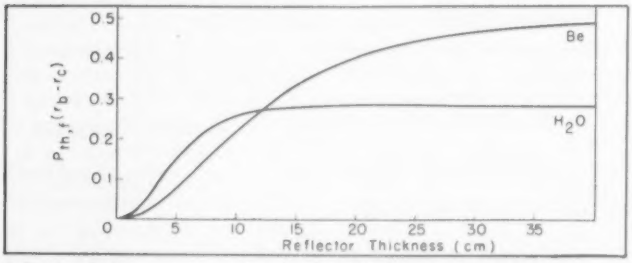

FIG. 3. Reflection parameter for beryllium and water reflectors

$$P_{th,f}(r_c) = \left[\frac{R_{0,f}}{R_{0,th}} - \frac{Z_f(r_c)}{Z_{th}(r_c)}\right]\left(\frac{g_{th,f}R_{0,th}}{\alpha_f^2 - \alpha_{th}^2}\right) \quad (13)$$

Illustrative values of $Z_f(r)$, $Z_{th}(r)$, and $P_{th,f}(r)$ are plotted in Figs. 2 and 3 for various thicknesses of simple water and beryllium reflectors for a spherical geometry and a core radius of 30 cm.

The neutron currents entering the reflector zone are therefore linear functions of the fast- and thermal-neutron fluxes at the reflector boundary.

Application of Parameters

A group of reflectors satisfactory from an engineering and nuclear standpoint can be further compared by a knowledge of $P_{th,f}$, Z_f, and Z_{th}, which give a description of the over-all behavior of the reflector. These quantities are particularly useful for a comparison of reflector properties in the case of a multireflector reactor where the problem is difficult to solve by ordinary two-group methods.

Simulator operation using reflector parameters. In a typical reactor criticality determination, the fast-neutron reflector network is replaced by a fast-neutron resistance equal to $Z_f(r_c)$ that terminates the electric network for the active zone. Measurements made on the network will then include that of the current through this terminating resistance. The thermal-neutron network for the reactor core is terminated by a resistance equal to $Z_{th}(r_c)$, the thermal-neutron diffusion impedance. In addition, a current $P_{th,f}(r_c)$ multiplied by that measured through the reflector fast-neutron resistance is introduced at the terminal point of the core network.

The over-all reflector parameters give the following advantages in simulator operation:

1. The network sections ordinarily assigned to the reflector can be used to give more detailed information of the neutron distribution in the reactor core.

2. The reduction in time required to set one resistor value and one current value in contrast to a large number of adjustments required for a reflector network greatly simplifies the operation of the simulator. This feature is especially useful for reactor calculations involving the adjustment of core parameters by iterative processes.

3. Various reflectors can be employed in calculations by the simple readjustment of one resistor value for each neutron group.

4. If a detailed variation in flux for a multizone reflector is required, the analytical expression with boundary values measured on the simulator gives more complete information than can be found with most practical reflector networks.

Numerical method. Equations 9–12 can be used to give new boundary conditions on the fluxes at the core-reflector interface. This will lead to a 2×2 determinant, which is approximately equal in complexity to the reduced form of the ordinary 4×4 determinant with 4 boundary conditions.

For a single core, having internal and external passive zones, the concept of reflector impedances and a $P_{th,f}(r)$ leads to a 4×4 determinant; there is no increase in the order of the determinant due to the addition of more passive zones. The conventional solution to the same problem requires an 8×8 determinant with 4 additional rows and columns for each additional passive zone. Thus, a considerable saving in computational effort and time should result from the use of the reflector-impedance method instead of the conventional method of solution of this particular problem.

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Age Determination of Uranium Minerals by the Pb-210 Method

If the ratio of Pb^{206} to Pb^{210} is known, the ages of uranium minerals can be calculated. Theory and experimental method for measuring the ratio are described here, and results for minerals from a number of classic localities are presented

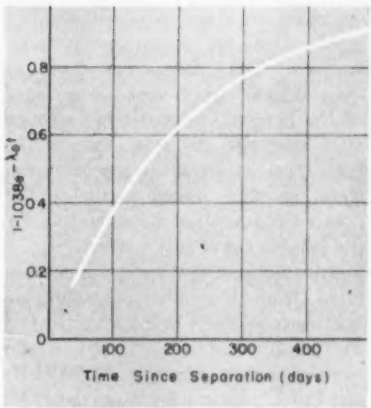

FIG. 1. Approach of Po^{210} to equilibrium with Pb^{210}

By J. LAURENCE KULP, WALLACE S. BROECKER, and WALTER R. ECKELMANN
Lamont Geological Observatory
Columbia University
Palisades, New York

MEASUREMENT OF the ratio of the quantity of Pb^{206} to the quantity of Pb^{210} contained in a uranium mineral provides a method of determining the age of the mineral.

The method, which would also provide a check on possible leaching of uranium, was first suggested in the literature by Houtermans (*1*), and was recently shown to be valid for Belgian Congo pitchblende by Begemann *et al.* (*2*). The main purpose of these authors was to establish the method as a simplification of the classic, "crude," lead age method, which consisted of measuring the ratio Pb/U. They did not discuss the problem of contamination by common lead, nor the use of the Pb^{206}/Pb^{210} value as a criterion of leaching.

The age of uranium bearing minerals has also been determined by measuring the Pb^{206}/U^{238}, Pb^{207}/U^{235} and Pb^{207}/Pb^{206} values. The Pb^{207}/Pb^{206} value is virtually unaffected by leaching of uranium late in the history of a mineral, which would point to the 207/206 age as being most reliable, were it not for the extreme sensitivity of this age to such factors as radon leakage, common-lead corrections, mass spectrometer error, and the half-life of U^{235}. This problem is particularly acute for ages less than 500-million years (Cambrian period) which constitutes the part of geologic history most fully described.

Theory

The age of a uranium-bearing mineral can be determined by the ratio of any one of the members of the decay series to the stable end product, providing the series is in equilibrium. Previous methods have employed the ratio of one of the uranium isotopes to its respective lead isotope. Equally good, theoretically, would be such ratios as Pb^{206}/Ra^{226}, Pb^{206}/Po^{214}, or Pb^{206}/Pb^{210}. However, the evaluation of each ratio involves practical difficulties; the half-lives may be too short or the chemical purification may be too complicated.

The Pb^{206}/Pb^{210} method is uniquely satisfactory for several reasons:

1. It is not necessary to carry out a quantitative analysis for uranium or lead.

2. The radioactivity measurement is quite simple.

3. It is actually difficult to contaminate the sample because the other members of the series, which might not be completely removed by chemical separation, either have such short half-lives that they would have decayed by the time the sample was counted or have such long lives that their contribution to the total activity would be negligible.

4. The half-life of Pb^{210} is about 22 yr.

5. Since uranium is more readily

leached than is lead or thorium, the Pb^{210}(RaD) should be in equilibrium with the 80,000-yr Th^{230}(Ionium) long after an appreciable quantity of uranium has been removed.

6. The chemistry involved is held to a minimum because the same sample used for a spectrometer analysis can be counted with no additional preparation.

The fraction of Pb^{206} in the sample is determined by isotopic analysis of the lead. If no common lead or appreciable thorium is present in the mineral, the fraction of Pb^{206} may be estimated to a few per cent without mass analysis for comparatively young samples. Thus, Begemann *et al.* (*2*) were able to obtain satisfactory ages on the Belgian Congo deposit without mass analysis. In most cases, however, these uncertainties are much too large, so that measurement of the isotopic composition is imperative for the reliable use of this method.

After the lead of the mineral is separated from the other elements, it first contains Pb^{214}(RaB), Pb^{210}(RaD), Pb^{211}(AcB), Pb^{206}, Pb^{207}, and, if the mineral contains thorium, Pb^{212}(ThB) and Pb^{208}. After a few hours the Pb^{214} and Pb^{211}, with their decay products, will have disappeared, and, after two days, even the Pb^{212} will be negligible.

This leaves only Pb^{210} with its decay products Bi^{210} and Po^{210}. Pb^{210}(RaD) is a weak beta emitter (0.025 Mev) with a half-life of 22.2 yr. Bi^{210}(RaE) is a strong beta emitter (1.17 Mev) with a half-life of 5.02 days, and Po^{210}(RaF) is alpha active (5.30 Mev) with a half-life of 138.3 days. In principle, the concentration of Pb^{210} can be measured by the activity of any one of these three isotopes if the time since separation of the lead is known. Each presents a separate problem.

The Pb^{210} emits such a weak beta that it should be counted in an internal gas counter. Lead tetramethyl, which can be prepared on a micro scale (*3*), is a suitable counting gas in low concentration and, hence, mixed with argon and ethylene, can be used in standard gas counters. That this method can be used to estimate the concentration of Pb^{210} has been demonstrated in this laboratory. However, it is not an easy or practical method for several reasons:

1. The absolute counter efficiency must be known.

2. The quantity of lead introduced into the counter must be accurately determined. It can be determined from a knowledge of the vapor pressure of $Pb(CH_3)_4$ if the micro quantity is highly purified. Another method would be to carry out a microanalysis for Pb in the counting gas after the counting is completed. Either method is time-consuming and difficult.

3. The immediate decay products (mostly RaE) are solid, and they deposit in the counter. This quickly raises the background to an unsatisfactory level.

The Bi^{210} can be measured with greater ease, as was done by Begemann

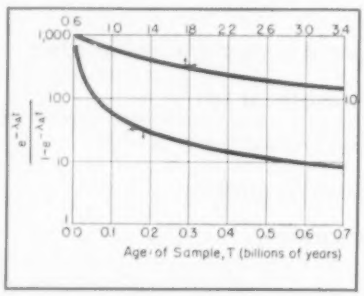

FIG. 2. The age relationship (second term in Eq. 8). Upper curve is continuation of lower curve

(*2*). Considerable effort is required in this method to obtain radioactively pure lead since the half-life of Th^{234} (UX_1) is about 24 days and, with its immediate product Pa^{234}(UX_2), is a strong beta emitter.

After purification, the lead salt is allowed to stand for several weeks so that equilibrium is established between the Pb^{210}(RaD) and the Bi^{210}(RaE). The strong Bi^{210} betas can then be readily measured in a dip-finger solution counter. Common lead and bismuth are added in nitric acid solution to avoid wall effects. In such an arrangement, the geometry is entirely reproducible but the density of the solution must be independently determined.

The absolute efficiency of the counter must be obtained with standard solutions. This method, which gives reproducibility of a few percent, is entirely usable but does require more elaborate chemical purification than the method to be described next.

If several months pass after the separation of $PbCl_2$ from a radioactive mineral, the Po^{210} alphas can be counted. Generally, equilibrium is not achieved ($t_{1/2}$ = 138.3 days), but enough time can be taken to allow all other interfering isotopes to decay. The solid alpha counting can then be done in a few minutes without modifying the lead salt in any way.

Calculation of the age. In deriving an expression for the age, T, of the mineral, in terms of the Po^{210} activity, the Pb^{210} concentration, and the time, t, since separation, it will be convenient to use subscripts to denote members of the decay series. The scheme of subscripts is as follows: A = U^{238}(UI), B = Pb^{210}(RaD), C = Bi^{210}(RaE), D = Po^{210}(RaF), and E = Pb^{206}(RaG).

The number, N_D, of Po^{210} atoms present at a time t after separation can be shown by standard methods to be given by

$$N_D = \lambda_B\lambda_C N_B' \left[\frac{e^{-\lambda_B t}}{(\lambda_C - \lambda_B)(\lambda_D - \lambda_B)} + \frac{e^{-\lambda_C t}}{(\lambda_B - \lambda_C)(\lambda_D - \lambda_C)} - \frac{e^{-\lambda_D t}}{(\lambda_B - \lambda_D)(\lambda_C - \lambda_D)} \right] \quad (1)$$

where N_B' is the number of B atoms at $t = 0$.

Since the half-life of Pb^{210} is much greater than that of Po^{210} and Bi^{210} we have $\lambda_B \ll \lambda_C$ and $\lambda_B \ll \lambda_D$.

Also, if t is small with respect to the half-life of Pb^{210} (or <2 yr), $e^{-\lambda_B t} \cong 1$. Furthermore, if the time, t, since separation is a month or more, $e^{-\lambda_C t} \cong 0$.

Therefore,

$$N_D = \frac{N_B'\lambda_B}{\lambda_D}\left(1 - \frac{\lambda_C}{(\lambda_C - \lambda_D)} e^{-\lambda_D t}\right) \quad (2)$$

If secular equilibrium existed in the radioactive mineral, then, at the time of separation,

$$\lambda_B N_B' = \lambda_A N_A' \quad (3)$$

$$N_A' = N_A^0 e^{-\lambda_A T} \quad (4)$$

$$N_B' = \frac{\lambda_A N_A^0 e^{-\lambda_A T}}{\lambda_B} \quad (5)$$

Since the sample to be counted is predominantly Pb^{206}, and since the fraction of Pb^{206} is known, it would be more convenient to have N_B' in terms of the number of Pb^{206} atoms present at $t = 0$ (N_E') than the number of U^{238} atoms at $T = 0$.

For $T >$ 10-million yr

$$N_E' = N_A^0 - N_A$$

$$N_E' = N_A^0(1 - e^{-\lambda_A T})$$

$$N_A^0 = \frac{N_E'}{(1 - e^{-\lambda_A T})}$$

and substitution in Eqs. 3, 4, and 5 gives

$$N_B' = \frac{\lambda_A N_E'}{\lambda_E} \frac{e^{-\lambda_A T}}{(1 - e^{-\lambda_A T})} \quad (6)$$

Hence, from Eq. 2,

$$N_D = \frac{\lambda_A N_E'}{\lambda_D} \frac{e^{-\lambda_A T}}{(1 - e^{-\lambda_A T})} \times \left[1 - \frac{\lambda_C}{\lambda_C - \lambda_D} e^{-\lambda_D t}\right] \quad (7)$$

Therefore, the alphas produced per minute by the Po^{210} at any time t after separation of the Pb^{210} from a mineral T years old is given by

$$N_D \lambda_D = \lambda_A N_E' \frac{e^{-\lambda_A T}}{(1 - e^{-\lambda_A T})} \times \left[1 - \frac{\lambda_C}{\lambda_C - \lambda_D} e^{-\lambda_D t}\right] \quad (8)$$

Thus, if the number of alphas produced in a sample, the time since separation, and the per cent Pb^{206} are known, the age T is the only remaining variable.

Figure 1, a plot of the last term of Eq. 8 against t, shows the approach to equilibrium of the Po^{210} after the separation of the lead. Figure 2 gives the final age relationship, the second term in Eq. 8.

Apparatus and Procedure

The absolute alpha activity of the Po^{210} is measured by the thick-source scintillation counting technique described by Kulp, Volchok, and Holland (*4*). The lead chloride, which has been separated from the uranium mineral by standard chemical procedures, is finely ground and placed in a tray 1 cm^2 in area. This tray is inserted $\frac{1}{32}$ in. below a 5819 photomultiplier tube (13-cm^2 sensitive area) that is coated with Patterson type-D silver-activated ZnS phosphor. The counting rate reproducibility of such an arrangement is better than 1%. The accuracy of the measurement of absolute alpha activity depends on the calibration, which should be done by using lead chloride with known concentrations of Pb^{210} or Po^{210}.

The calibration can be done in several ways. In the first method, an accurately known quantity of radon is allowed to decay to Pb^{210}, and weighed quantity of soluble lead salt is used to extract the Pb^{210} and act as a carrier. The lead is then precipitated as $PbCl_2$ which is used for the calibration.

Another, less desirable, method is to add trace quantities of Po^{210} to nonradioactive lead chloride. A third method of determining the counter efficiency for Po^{210} alphas in $PbCl_2$ consists simply of measuring the alpha activity of the lead chloride of a mineral of known age.

The last method, using several pitchblendes of known age, is the one that was used for preliminary calibration. The absolute efficiency determined in this manner was 67.7 ± 2.2%.

The fraction of Pb^{206} in the sample is determined from the isotopic analysis. After the Pb^{210} measurement has been carried out, the $PbCl_2$ sample is converted to $Pb(CH_3)_4$. The lead tetramethyl is isotopically analyzed in a Nier-type 60-deg mass spectrometer. These procedures will be described elsewhere (*5*).

Results

The results of measurements on a number of samples are given in the table. The ages obtained by the Pb^{210} method are listed along with the "best" age. The latter is the age determined from an analysis of the available 206/238, 207/235, 208/232, and 207/206 values for the locality involved. The primary sources for this analysis are the papers by Nier (*6*), Collins (*7*), and Kulp (*5*). The data used in arriving at the "best" age were weighed according to their probable errors. In general, the 206/238, 207/235, and 208/232 ages are considered more reliable than are the 207/206 ages.

It is seen that the results are in excellent agreement over a range of ages from 60- to 1,400-million years, which establishes the validity of the Pb^{210} age method as described.

Further, the consistency shows that the effect of leaching on all of these samples has been negligible. If uranium were leached from the mineral, the "best" age, which is largely derived from 206/238 and 207/236 ages, would be high.

The Pb^{210} age is independent of radon leakage if the radon leakage has been constant. Therefore, the agreement between 206/238 and 206/210 ages suggests that radon leakage could not have been more than a few per cent for this type of uranium mineral.

* *

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Comparison of Pb^{206}/Pb^{210} Ages with "Best" Age

Lamont sample no.	*Mineral*	*Locality*	*"Best" age (10^6 yr)*	*Pb^{206}/Pb^{210} age (10^6 yr)*
K-8	Pitchblende	German Mine, Central City, Colo.	59 ± 5	58 ± 3
K-6	Pitchblende	Rickards Mine, Gilpin Co., Colo.	60 ± 3	61 ± 3
K-15	Pitchblende	St. Joachimsthal, Czechoslovakia	200 ± 20	206 ± 10
K-4	Samarskite	Wiseman Mine, Spruce Pine, N.C.	340 ± 20	325 ± 15
K-9	Pitchblende	Katanga, Belgian Congo	620 ± 20	650 ± 15
K-19	Uraninite ore	Nicholson Mine, Saskatchewan	800 ± 50	808 ± 25
K-7	Pitchblende	Contact Lake, N. W. Territory	879 ± 30	864 ± 35
K-16	Uraninite ore	Eldorado Mine, Great Bear Lake	1,250 ± 30	1,208 ± 40
K-20	Uraninite concentrate	Witwatersrand, So. Africa	1,320 ± 50	1,290 ± 40
K-14	Uraninite ore	Eagle Mine, Athabasca	1,430 ± 20	1,448 ± 35

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Deposition of Airborne Radioiodine Vapor

Radioiodine vapors in the air can be a hazard if absorbed by vegetation. Measurements of the rate at which the isotope is deposited on or absorbed by grass are described, and permissible output from stacks is calculated

By A. C. CHAMBERLAIN and R. C. CHADWICK
Atomic Energy Research Establishment
Health Physics Division
Harwell, England

THE ABSORPTION (or adsorption) by vegetation of volatile fission products released from radiochemistry laboratories or atomic energy chemical separation plants may give rise to potential hazards. Iodine-131 is particularly important in this respect because:

1. It has a high fission yield.

2. Although volatile at ordinary temperatures, it is strongly absorbed or adsorbed and held by cellulose-like materials and by dusts, when in carrier-free form.

3. It is concentrated in the thyroid glands of animals, its maximum permissible level in the human body being no more than 0.3 μc; maximum permissible level in air for continuous breathing is $3 \times 10^{-9} \mu c/cm^3$ (*1*).

The determination of the maximum permissible level of I^{131} over pasture land requires the determination of the maximum permissible level in grass, which has been considered by Parker (*2*), and the rate at which I^{131} is deposited on or absorbed by grass from the air, which is the subject of the experiments described here.

It was not intended to study the eddy diffusion of the vapor in the air, for which an adequate theory exists (*3*), except in relation to the deposition.

Dissemination, Collection of I^{131}

At each trial, elemental, carrier-free* I^{131} in carbon tetrachloride was sprayed up as a mist of minute droplets from a Collison spray, at a height of 50 cm above a grass airfield. The carbon tetrachloride rapidly evaporated as the cloud passed downwind towards the sampling positions (Fig. 1), leaving a vapor of iodine.

The source was liberated over a period of about 20 min, and during the whole of this time the cloud was sampled at selected points downwind by drawing air at a known rate through caustic soda bubblers, by means of injectors fitted to compressed-air bottles. The air samplers measured the time integral of the volumetric concentration of activity, or dosage, as it will be called.

Samples were taken at heights of 25 and 50 cm above ground, except in the first experiment in which sampling was at 25 cm only. The dosage of activity at 50 cm was, on the average, a few per cent higher than that at 25 cm, but individual random variations between sampling positions were considerable, and, to reduce random errors, the means of air samples at each position have been used in the analysis.

Near the volumetric sampling points, Petri dishes containing 9-cm disks of Whatman No. 4 filter paper were exposed. Preliminary experiments had shown that the filter paper acts as a very good absorbent for carrier-free I^{131} vapor, with negligible loss by re-evaporation. The estimation of the I^{131} activity on the papers could be done very simply by end-window counting, and the papers provided a convenient index of the physical factors influencing deposition.

Grass samples were taken by mowing as closely as possible 1 ft^2 of ground. In the earlier experiments, the activity in these samples was estimated by chemical extraction following chromic acid oxidation of the vegetation, but it was later found easier and more accurate to count macerated samples under an end-window counter. This method was used in the last three trials and enabled more samples to be analyzed with a reduction in the error of the mean.

Layout of Trials

The deposition of the sampling points varied between trials. In the first trial, two arcs were set up, at 15 and 30 meters from the source, sufficient to cover the whole width of the cloud of I^{131}, although grass samples were taken in the nearer arc only. In the later experiments, the number of sampling points was reduced, as it was thought important to duplicate the measurements at each point, and the full width of the cloud was not sampled in every case.

Results of First Trial

The first trial will be described in full, and a summary given of the results of the others. The first trial was not the most satisfactory as regards the grass measurements, but it included complete filter-paper measurements from which some general conclusions could be drawn.

A solution of 27 mc of "carrier-free" I^{131} in carbon tetrachloride solution was used, but an unknown fraction of the activity remained behind after the solution had been sprayed up; presumably it was adsorbed on the glass.

The dosage of I^{131} activity at 25 cm above ground, measured at points spaced 1.5 m apart on the 15-m arc, and 3 m apart on the 30-m arc, is shown in Fig. 2. The deposition of activity to the filter papers in Petri dishes, measured at the same points,

* The I^{131}, prepared by irradiation of tellurium, contained up to 5μg/mc of inactive iodine, due to impurities in the tellurium.

FIG. 1. Sampling apparatus in position on airfield

is shown in Fig. 3. The Gaussian curves of best fit are drawn in. The fit is reasonable for the 15-m arc and good for the 30-m arc.

The crosswind distribution can be described by two parameters, the distance of the center of the curve from the zero point on the arc, and the standard deviation. The parameters of corresponding curves are nearly identical, as shown in Table 1.

It follows that the ratio of the amount of deposited activity per square centimeter to the dosage of activity per cubic centimeter of air is constant along the sampling arcs. This ratio, which has the dimensions of velocity, will be called the velocity of deposition. Since the velocity of deposition is not dependent on the dosage, in the range of the experiment, it follows that the absorptive capacity of the paper is not a limiting factor on the deposition.

The average velocity of deposition is equal to the ratio of the areas under the corresponding curves of Figs. 2 and 3. Alternatively, a mean value can be obtained by averaging the ratios of individual readings, and this has the advantage that the standard error of the mean can be deduced from these values. Table 2 shows this data for the first trial.

The velocity of deposition is not significantly different in the two arcs, which suggests that the gradient of activity with height very near the ground, and other factors determining the deposition, had reached a stable state by the time the cloud had reached the nearer arc.

Measurements of I^{131} activity on the grass were made at four points only, midway between air-sampling positions on the 15-m arc. The mean density of herbage was 50 mg/cm² of ground. The activities found, expressed as micromicrocuries per square centimeter of ground, are compared in Table 3 with the air dosages read off from the 15-m-arc graph of Fig. 2.

The velocity of deposition to grass is more variable than that to filter paper. The mean value is 1.91 cm/sec, and the standard error, if an estimate can be made with only four readings, 0.32 cm/sec.

The velocity of deposition to grass, per square centimeter of ground, was three times that to filter paper in Petri dishes, but this does not mean that grass leaf has a greater affinity for iodine than has paper. The area of leaf growing on 1 cm² of ground is much greater than 1 cm². This point will be returned to later.

Meteorological Data

The wind velocity profile is shown in Fig. 4. The method of plotting the wind speed against height, and the symbols, are those commonly used in studies of the meteorology of the lower atmosphere and are explained by Sutton (4). The relation between wind velocity, u, and friction velocity, v^*, is

$$u/v^* = (1/0.4) \log (z - d)/z_0$$

The correction, d, to the height, z, above the ground, which is necessary to allow for the layer of still air trapped in the grass, had the value 10 cm. It was determined empirically as the correction necessary to reduce to a straight-line plot values of u and $\log z$ obtained in a number of profile measurements. The lapse rate for trial 1 was 1.4° F in 30 ft.

The roughness parameter, z_0, was found to have the value 2.8 cm, which is in the range of values given by Sutton for moderately long grass.

Results of All Experiments

In Table 4 the results of all the field trials are summarized. The last two were done on the afternoon and evening of the same day on adjacent parts of the airfield, and the nature of the terrain was therefore the same for both although the wind velocity and light conditions were different. These two trials, and trial 1, were done when there was a good growth of grass, which is

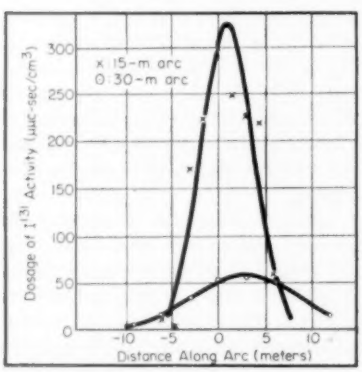

FIG. 2. Radioiodine in air

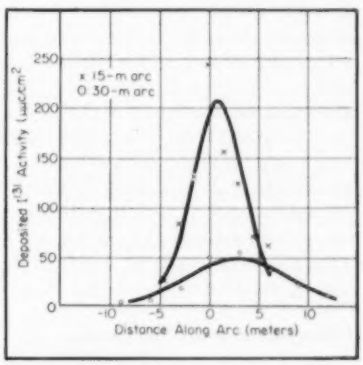

FIG. 3. Radioiodine on filter papers

TABLE 1—Parameters for Crosswind Activity Distributions (Trial 1)

	Ordinate of center (m)	*Standard deviation (m)*
Volumetric activity, 15-m arc	1.07	2.72
Deposited activity, 15-m arc	0.88	2.71
Volumetric activity, 30-m arc	2.87	5.48
Deposited activity, 30-m arc	3.09	5.33

TABLE 2—Velocity of Deposition to Filter Paper (Trial 1)

	15-m arc	*30-m arc*
Ratio of area under curves	0.64	0.78
Mean of ratios of individual readings	0.64	0.67
Standard error of mean	0.10	0.08

TABLE 3—Velocity of Deposition to Grass (Trial 1)

Distance from center of arc (m)	*Activity in grass ($\mu\mu c/cm^2$ ground)*	*Air dosage ($\mu\mu c$-sec/cm^3)*	*Velocity of deposition (cm/sec)*
−5.25	37	23	1.61
−2.25	350	155	2.26
+2.25	350	295	1.19
+5.25	260	100	2.60

TABLE 4—Summary of Results of Experiments

Trial	*Time (G.M.T.)*	*Date*	*Weight of grass (wet) (mg/cm^2)*	*Weather*	*Wind velocity (cm/sec) 2m*	*Wind velocity (cm/sec) 1m*	*Friction velocity (cm/sec)*	*Roughness parameter (cm)*	*Velocity of deposition (cm/sec) To grass (per unit area of ground) Mean*	*S.E.*	*To filter paper Mean*	*S.E.*
1	1820	8/5/49	50	50° F, sunny	520	420	48	2.8	1.91	0.32	0.64	0.10
2	1700	8/8/50	20	65° F, cloudy	433	372	35	1.5	2.65	0.50	0.72	0.19
3	1300	3/7/51	26	68° F, sunny	515	442	48	1.2	1.79	0.21	0.94	0.13
4	1700	8/8/51	42	69° F, sunny	408	310	38	2.4	3.75	0.19	0.65	0.18
5	2200	8/8/51	42	61° F, nearly dark	165	138	15	2.4	1.72	0.27	0.30	0.04

reflected in the relatively high value of the roughness parameter z_0. Trials 2 and 3 were done at times when the growth had not recovered from the annual hay crop.

The rate of deposition of the iodine on the vegetation is probably affected by (a) aerodynamical factors, including wind velocity and velocity gradient near the ground; (b) type of herbage, herbage density, and conformation; and (c) metabolic state of leaves, in particular whether the stomata are open or closed.

In a series of trials in which all these factors varied together, no great consistency of results could be expected. It is interesting, however, that the rate of deposition in trial 5, after dusk on a warm August day, was only half of the rate of deposition at 1700 hours in the afternoon of the same day (trial 4). On the other hand, the rate at 1300 hours on an equally warm day a month earlier (trial 3) was equally low. A possible explanation is that this last-named experiment was carried out at a time when the pasture was very dry and parched.

Living and Inert Surfaces

In an attempt to gain some knowledge of the factors limiting the rate of deposition of the iodine, a number of experiments were performed in which paper-covered sheets of metal were exposed to the iodine vapor, both in the field and in a small-scale wind tunnel, which was operated at wind speeds similar to those found in the open air.

It was found that the rate of deposition of I^{131} vapor onto filter paper, both in the wind tunnel and in the open air, is controlled by the rate at which diffusion brings the molecules into contact with the paper. The deposition is equal at equivalent points on the upper and lower surfaces of plane sheets of metal covered with filter paper. It is greater near the upwind edge of the sheet than it is in the middle. The process of deposition is in many ways analogous to the process of evaporation of water and other liquids from saturated surfaces, for which diffusion is also the controlling factor (*5*).

Paper "leaves," made of appropriately shaped pieces of Whatman No. 4 filter paper attached to growing plants, were then exposed to the iodine in the open air and in the wind tunnel, and comparisons were made of the deposition on the leaves of the plant and on the filter paper. These experiments were done in collaboration with Dr. R. Scott Russell, of the School of Agriculture at Oxford. The following facts of a qualitative character have been established:

1. In experiments done so far with clover, dandelion, and bean plants, the ratio of the deposition on the leaves of living plants to the deposition on similarly shaped pieces of filter paper has always been less than one.

2. The ratio has been more nearly unity in good light than in poor light or darkness.

A reasonable hypothesis is that the rate at which diffusion brings the iodine into contact with the leaf is an over-riding limiting factor on the uptake by the plant, which, however, may be further limited by the absorptive capacity of the leaf, dependent on the metabolic state, and in particular on whether the stomata are open or closed.

An autoradiograph of parts of two dandelion leaves, cut immediately after a 20-min exposure to I^{131} vapor, and of a piece of filter paper exposed with them, is shown in Fig. 5. A considerable degree of localization of the I^{131} in the veins of the leaf is noticeable,

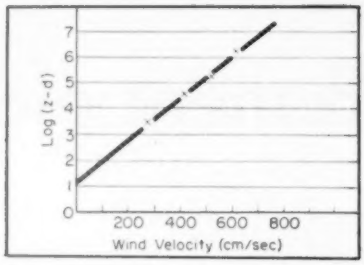

FIG. 4. Wind velocity profile (trial 1)

TABLE 5—Permissible Output of I^{131} from Stacks

Height of stack (*m*)	*Maximum time-average concentration for an emission of 1 curie/day* ($\mu c/cm^3$)	*Permissible daily output of* I^{131} (*mc*)
10	1×10^{-10}	10
25	3×10^{-11}	40
50	7×10^{-12}	150
100	2×10^{-12}	500

indicating that some translocation of the iodine was in process.

As a check against the possibility of pressure effects, unexposed leaves have also been autoradiographed. The only detectable result was a slight bleaching effect on the negative, due probably to chemical action.

Biological Half-Life in Herbage

Measurements on samples of herbage collected at intervals after the dissemination of the iodine showed that the removal of carrier-free I^{131} from the grass by translocation and leaching by rain was appreciable, but not large in comparison with the radioactive decay. The activity of the herbage appeared to decay with a half-life of 5 or 6 days, compared with the radioactive half-life of 8 days.

Permissible Level for Pasture

The maximum permissible level of I^{131} in herbage was given as 2×10^{-4} μc/gm by Parker (*2*) on the assumptions (a) that a cow eats 10 lb of herbage a day, and (b) that it may be allowed to receive a dose of 1 r/day to the thyroid.

The figure assumed by Parker for the amount of grass eaten per day is low for British animals, and the recommended British maximum permissible level is 1×10^{-4} μc/gm (*6*).

To deduce the average air concentration that will result in a grass activity of 1×10^{-4} μc/gm being just maintained, the rate at which I^{131} is deposited on the grass must be equated to the rate at which the activity disappears by radioactive decay and other means.

Let C = average concentration of I^{131} in air ($\mu c/cm^3$); v_g = velocity of deposition of iodine vapor as defined above; V = resulting stationary I^{131} concentration in herbage (μc/gm wet weight); m = wet weight of herbage in mg/cm² of ground; and T = effective half-life of I^{131} in herbage, in sec. Then the equation

$$Cv_g = (Vm/1{,}000)(0.693/T)$$

expresses the condition that the rate of deposition is equal to the rate of decay.

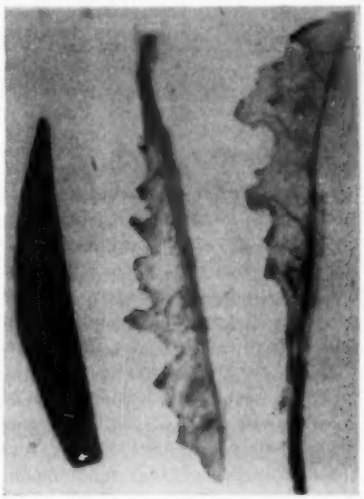

FIG. 5. Autoradiographs of dandelion leaves and filter paper exposed to radioiodine vapor

The results of the experiments show that, on the average, $v_g = 2.5$ cm/sec, and $T = 5 \times 10^5$ sec. Taking $m = 20$, corresponding to a rather thin covering of grass, and putting V equal to the maximum permissible concentration of I^{131} in grass (10^{-4} μc/gm), then, C_0, the maximum permissible average air concentration is

$$C_0 = \frac{10^{-4} \times 20 \times 0.693}{1{,}000 \times 5 \times 10^5 \times 2.5} = 1 \times 10^{-12} \mu c/cm^3$$

This is less by a factor of 3,000 than the human breathing tolerance quoted above, indicating that the uptake onto grass is likely to be the limiting factor in determining the amount of I^{131} activity that can be liberated over pasture or market garden areas.

Permissible Output from Stacks

The formulas of Sutton (*3*) for the diffusion of smoke from factory chimneys enable an estimate to be made of the permissible output of I^{131} from stacks of various heights, such that the average concentration over long periods at ground level nowhere exceeds 10^{-12} $\mu c/cm^3$.

Sutton's formulas are given in terms of the instantaneous concentration of smoke at various distances downwind of the stack. To deduce the time-average concentration at the worst place, which is in the direction of the prevailing wind at a distance from the stack equal to about 20 times the stack height, it is necessary to integrate the effects due to winds of all directions and to allow also for the fact that certain wind directions are more common than others. An average wind speed of 5 m/sec is assumed.

The calculations are very approximate, and probably err on the side of overestimating the concentration at ground level. The results are given in Table 5.

* * *

We are indebted to the Isotope Division at AERE for supplying the I^{131} *and calibrating the counters used, and to the Meteorological Group and Mr. W. G. Bushbridge for assistance with the field experiments. We are indebted also to Dr. R. Scott Russell, of the School of Agriculture, Oxford University, for helpful advice, and to the Director, AERE, for permission to publish this paper.*

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Film Measurement of

Simple, fast measurements of beta-ray depth dose can be made with photographic films. Response curves for seven emulsions are presented here. Comparison with more laborious extrapolation-chamber measurements shows that the film method is accurate

By E. TOCHILIN and R. GOLDEN
U. S. Naval Radiological Defense Laboratory
San Francisco, California

THE HIGH resolving power of film and its sensitivity to ionizing radiation make it possible to determine with great exactness the distribution of radioactive material in tissue. Autoradiographs of isotopes deposited in thyroid tissue and in bone are familiar in radioisotope work. Work by Dudley and Dobyns indicates that, with proper calibration techniques, a quantitative evaluation of dosage received can be obtained using the autoradiographic technique (*1*).

Similarly, the use of photographic emulsions to measure depth-dose from beta-ray plaques through tissue would be of great value. Beta-ray isotopes are used to some degree as medical applicators in clinical work for the treatment of surface lesions. In some instances, individual sources are prepared for each treatment and are contoured to the size of the area being treated (*2*). Under such conditions, it would be of considerable value to determine by a simple dosimetric technique the surface dose together with the distribution of dose in the tissue. Extrapolation chamber measurements are used for this purpose. Such instruments serve as primary standards for the measurement of beta radiation but are not readily available at most laboratories.

The purpose of these experiments was to investigate film response to beta radiation and to establish conditions under which quantitative depth-dose measurements with film are possible.

Apparatus

Table 1 lists the isotopes used for the beta-ray film measurements together with the maximum energies of their beta spectra. The various films used, together with their thicknesses, developing times, and beta-ray sensitivities are shown in Table 2. Films

TABLE 1—Standard Beta Sources

Source	*Half-life*	*Maximum energy (Mev)*	*Filters* (mg/cm²)*
Tm^{169}	117 d	0.50	None
RaD+	22 y	0.026	25
RaE	5 d	1.17	
Y^{91}	57 d	1.54	None
Sr^{90}+	20 y	0.53	100
Y^{90}	62 h	2.18	
Ru^{106}+	1 y	0.041	Flash plating of silver
Rh^{106}	30 s	2.30(18%)	
		3.55(82%)	

* Used to eliminate low-energy beta components.

TABLE 2—Beta-Ray Sensitivity of Films Used for Depth-Dose Measurements

Film	*Developing time at 68° F (min)*	*Maximum usable density*	*Approximate dose at maximum density (rep)*	*Film thickness (mg/cm²)*
Eastman Type K	5	6.0	6	33.6
DuPont 552, Sens.	5	3.0	10	32.0
DuPont 552, Insens.	3	6.0	70	28.6
Eastman DF-7	8	6.0	80	26.8
Eastman 5302	10	4.0	400	20.2
Eastman Translite	5	5.0	2,000	21.6
Eastman 548-0	10	4.5	20,000	30.3

Beta-Ray Depth Dose

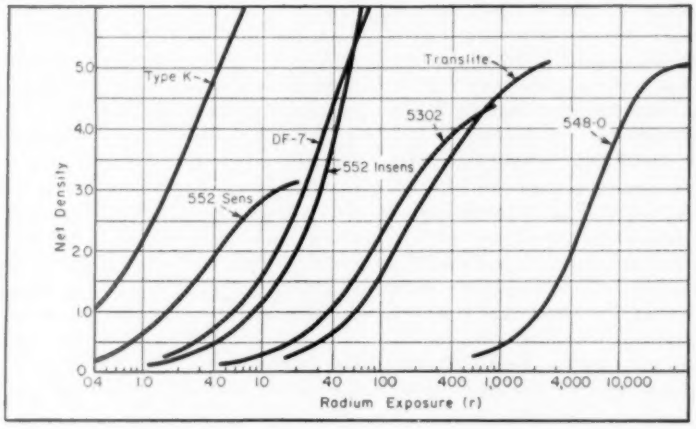

FIG. 1. Characteristic curves for seven films

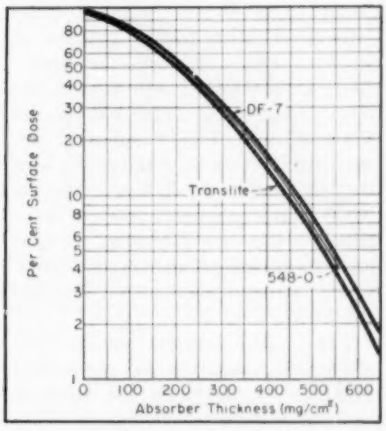

FIG. 2. Depth-dose curves of three films for Sr^{90} source

were chosen to allow depth-dose measurements over a range of beta-ray dosages extending to approximately 20,000 roentgen equivalent physical.

The films were developed in Kodak Liquid X-Ray Developer. The developing times used for the various emulsions (at a temperature of 68° F) are given in Table 2. No agitation was used during development. The films were fixed for 10 min in Kodak X-Ray Fixer, washed for 20 min in running water, rinsed in a water solution containing a wetting agent, and then dried.

An Ansco color densitometer was used to measure the density of the processed film. With this instrument, film densities can be read to a value of 6.0.

All film measurements were made using dental-size film packaged in a molded rubber film holder ¾ in. deep. The holder was filled with alternate layers of film and black-paper spacers. The loaded holder, containing some 60 dental films, was covered with black paper.

These film holders had been produced in quantity to measure beta-ray energies of fission-product contaminants spread over a large area. Under laboratory conditions such an elaborate film holder is hardly necessary. Dental-type films can be packaged and exposed in almost any type of improvised container. If the emulsion desired is more readily obtained in sheet form, it can be cut to a convenient size and packaged in a similar manner.

Four of the emulsions used were obtained on a special order from the Eastman Kodak Co. These were Eastman DF-7 Radiatized dental film, Eastman Cine Positive film, Eastman Translite film, and Eastman 548-0 spectroscopic film. They were cut to standard dental film size and packaged 200 to a box with a black paper spacer between adjacent films. The remaining films, Eastman Type K and DuPont 552 sensitive and insensitive films, are commercially available in dental film size.

Film Sensitometry

Characteristic curves for the various photographic emulsions were obtained by exposing the films to gamma rays from a radium source and developing for the times listed in Table 2. The resultant characteristic curves are plotted in Fig. 1. They afford a comparison of the relative gamma-ray sensitivities of the different emulsions over the entire range of readable densities.

As will be shown, the gamma-ray sensitivities assigned the various films are essentially their beta-ray sensitivities. Within specific limits of beta-ray energy, the same film density will be produced with a roentgen-equivalent-physical of beta radiation as with a roentgen of gamma radiation.

A characteristic curve serves to define completely the response of film to radiation over its entire range of usable densities. Normal film dosimetry practice consists of running a calibration curve (processing a set of films which have received a known exposure) together with each group of films developed, thereby minimizing errors that might arise from the many variable factors involved in the developing process. This procedure was followed for all of the beta-ray film measurements described here.

It is of interest to note that the shape of the characteristic curve for a given film is substantially independent of the energy of the exposing electrons or photons, provided they are able to penetrate the entire thickness of emulsion. For a double-coated film this would mean that the ionizing particle must have sufficient energy to penetrate the entire film. In the case where an electron does not have suffi-

cient energy to penetrate the emulsion completely, the resultant characteristic curve would be similar to one obtained with a film having a thinner coating of the same emulsion.

To check the response of the various films to beta radiation, depth-dose curves were run by exposing the entire group of films to a Sr^{90} medical applicator at a source-to-film distance of 3.8 cm. Figure 2 shows the depth-dose curves obtained with three of the seven films used. The curves for Translite and DF-7 represent the maximum difference obtained for any two films. The depth-dose curve for 548-0 film represents the average between the two extremes. Curves for the remaining four films, if plotted, would fall between those of Translite and DF-7.

The slight differences observed are attributed primarily to errors encountered in measuring the depth of the various films rather than to differences in film sensitivity. The results indicate that, in making depth-dose measurements, the response of film to beta radiation is essentially independent of the type of emulsion used.

Only two of the films used for depth-dose measurements were single-coated emulsions, namely, Eastman 5302 and 548-0. In this instance, the depth to any particular emulsion was clearly defined. With the double-coated emulsions, both sides of the film were blackened by radiation. The difference in blackening of the two sides is due to the amount of ionization absorbed in the cellulose acetate film base. It has been assumed that the total blackening of such films represents the sum of two densities, and that this density occurs in the middle of the film. The depth to the sensitive area of a double-coated emulsion then becomes the depth to the top surface plus one-half the thickness of the film.

Beta-Ray Sensitivity

For purposes of personnel monitoring, the response of photographic film to beta-ray isotopes of maximum energies varying from 0.26 to 3.5 Mev has been investigated by Storm (*3*). The film was found to be much less sensitive to low-energy beta radiation than to high-energy beta radiation, becoming nearly independent of energy above 2.5 Mev. Because all exposures were made with the film enclosed in a dental-type packet, and because double-coated film was used, this information is not sufficient to determine the absolute beta-ray sensitivity of film over the range indicated.

The response of film to low-energy radiation is influenced in part by the absorption of beta radiation in the paper wrapper. A further decrease in film response is due to absorption in the cellulose acetate base on which the emulsion is coated, thereby affecting the amount of radiation reaching the bottom emulsion as compared to the top emulsion.

To evaluate the absolute sensitivity of film over a range of beta-ray energies would require the use of a single-coated emulsion thin enough so that negligible beta-ray absorption would occur. To obtain such data, the response of Eastman DF-19, a dental-type film having emulsion on one side only and an emulsion thickness of 2.4 mg/cm², was investigated using beta-ray isotopes ranging in maximum energy from 0.5 to 3.55 Mev (Table 1). Eastman DF-19 film has the same emulsion as Eastman DF-7, one of the films used for the beta-ray depth-dose measurements. Exposures were made using a source-to-film distance of 12.0 cm, at which distance the outputs of the sources were calibrated with an extrapolation chamber.

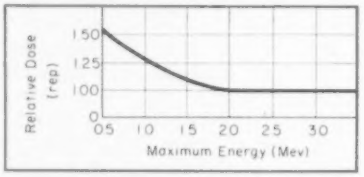

FIG. 3. Beta sensitivity of Eastman DF-19 film for density of 1.0

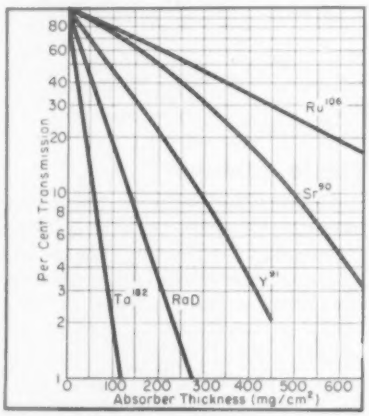

FIG. 4. Aluminum absorption curves for five beta emitters

Figure 3 shows the response of Eastman DF-19 film over the range of beta-ray energies investigated. All exposures are given relative to the roentgen-equivalent-physical dose required to produce a density of 1.0 with the Sr^{90} source (2.18 Mev). A marked decrease in film sensitivity is observed for the lower energies. To produce the same film density with a 0.5-Mev as with a 3.5-Mev beta-ray isotope required an increase in ionization exposure by a factor of 1.5.

The film sensitivity is essentially constant for beta-ray energies greater than 2.0 Mev. For these energies, the films are equally sensitive to both beta and gamma radiation. Film densities identical within 5% were observed for a gamma-ray exposure of 1 r (using radium) and for a beta-ray exposure of 1 rep (using Sr^{90}). On this basis the gamma-ray sensitivities assigned the various films in Fig. 1 are also their beta-ray sensitivities.

The response of photographic film to electrons has been studied by Fleeman and Frantz (*4*) for energies ranging from 0.5 to 1.4 Mev. Within these limits, film response was found to be proportional to the dose received and independent of the energy of the incident electrons.

Dudley (*5*) has extended this study to include electrons of very low energies. In this region, Dudley observed that, for perpendicularly incident electrons, the dosage sensitivity of five different films is strongly dependent upon energy. The sensitivity starts at zero for zero energy, rises to a peak at approximately 0.1 Mev, and thereafter decreases to a plateau of one-third to two-thirds maximum sensitivity for energies greater than 0.5 Mev.

For diffuse incidence, which is the condition occurring when a beta-ray plaque is placed directly on film, the dosage sensitivity increases with energy, reaching a flat maximum at 1 Mev. The initial rise, between 0 and 0.1 Mev, is rapid, the sensitivity at 0.1 Mev being about two-thirds of the maximum. The numerical values cited were influenced by the emulsion thickness and the ratio of silver halide to gelatin of the various films investigated.

Depth-Dose Measurements

Figure 4 shows a series of aluminum absorption curves obtained with an extrapolation-type ionization chamber

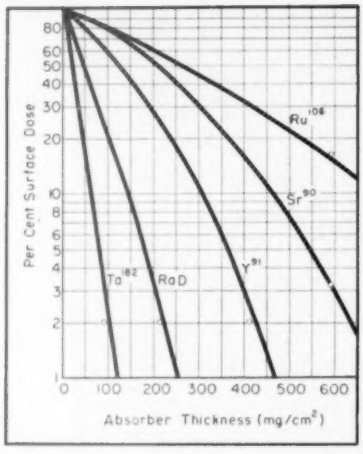

FIG. 5. Depth-dose curves obtained with film for five beta emitters. Circles are normalized points from the Al absorption curves of Fig. 4

using beta-ray isotopes ranging in maximum energy from 0.5 to 3.5 Mev. At low energies, exponential absorption is observed over the entire range of absorbers used. At higher energies, the curves approach exponential absorption beyond several half-thicknesses of absorbers (a half-thickness of absorber will reduce the beam intensity to one-half of the initial value).

Dudley, who has studied the problem of beta-ray absorption, has suggested the following two conditions as explaining the exponential absorption of beta rays (*5*):

1. The energy spectrum must remain nearly uniform under absorption.

2. The angular distribution pattern of the beta radiation must remain substantially constant under absorption.

Both conditions are necessary to produce the experimentally observed absorption properties.

Brownell (*6*) has measured the energy spectrum of P^{32} before and after the addition of various absorbers and backscatterers. He found a relatively slow variation of average energy with absorber thickness, indicating that the beta-ray spectrum is reasonably uniform under absorption. This is possible because the low-energy beta rays are more rapidly absorbed out of the beam than are the high-energy particles, and, despite the continual loss of energy by each beta particle, equilibrium is approached between the number of low-energy electrons formed and the number absorbed. In this way the average energy decreases very slowly with increasing absorber thickness.

Brownell has also observed that the angular distribution of radiation approaches an equilibrium after several half-thicknesses of absorber. For Lucite absorbers, a cosine-law distribution was established which remained constant over the range of absorbers used. Since Lucite is similar to tissue in electron density, this would be the distribution to be expected in tissue. If uniform spectral distribution and angular distribution are maintained under absorption, it then becomes possible to obtain a quantitative measure of depth-dose using photographic film.

Depth-dose measurements are primarily influenced by absorption, scattering, and geometry (inverse-square-law) considerations. At distances where inverse-square-law effects become negligible, depth-dose curves would be expected to be similar to absorption curves. This condition assumes that the ratio of primary to secondary radiation would remain essentially constant throughout the depth of measurement. This is a reasonable assumption for beta rays once equilibrium conditions have been established.

Figure 5 shows the depth-dose curves obtained with photographic film at a source-to-film distance of 3.8 cm. These curves are compared with absorption measurement of the same isotopes illustrated in Fig. 4. Although differences in geometry and absorbers preclude a direct comparison of the two measurements, it is apparent that for any particular isotope the two curves are quite similar.

Since, for beta rays, energy loss is proportional to the mass stopping power of the absorber, the two curves can be further normalized by taking into account the ratio of the stopping powers of the cellulose acetate film base and the aluminum. An average mass stopping power of polystyrene relative to aluminum, calculated by Sheppard and Abele to be 1.10, has been used (*7*). The circles adjoining each of the depth-dose curves of Fig. 5 show where one point taken from the aluminum absorption curves of Fig. 4 would fall when normalized in the manner stated above.

With the assistance of J. S. Krohmer of Western Reserve University, surface depth-dose measurements using photographic film were compared with extra-

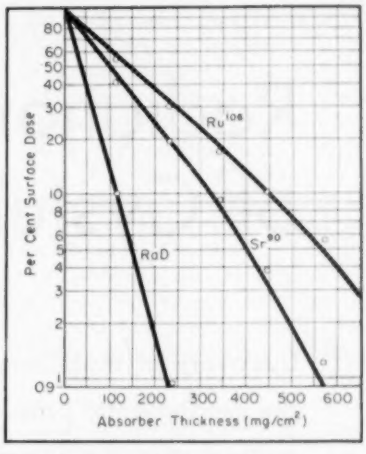

FIG. 6. Comparison of film and extrapolation chamber depth-dose curves. Solid lines obtained with film, circles with extrapolation chamber

polation chamber measurements of the same sources. The films were exposed at Western Reserve and mailed to this laboratory, where they were processed and compared with extrapolation chamber curves obtained by Krohmer (*8*).

Results of the comparison for three sources, RaD, Sr^{90}, and Ru^{106} are shown in Fig. 6. The curves were obtained with photographic film; the circles represent the experimental points obtained with the extrapolation chamber. To a depth-dose of 10% the agreement is excellent. Below this value, differences became apparent, primarily at higher energies where the average beta-ray energy is significantly changing with increasing absorber thickness.

The information presented in Fig. 6 is sufficient to allow the use of film depth-dose measurements for radiotherapy purposes or for any quantitative evaluation of the distribution of beta radiation in tissue.

* * *

The authors wish to thank Mr. J. S. Krohmer of Western Reserve University for his valuable assistance, which made possible the comparison of photographic and ionization chamber depth-dose measurements.

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Radiation Chemistry of Cysteine Solutions

Discovery of modifications produced in proteins by radiation is one of the fundamental problems of radiobiology. Studies with amino acid solutions help to give an understanding of this problem

By S. L. WHITCHER,* MARY ROTHERAM, and NORMAN TODD
Atomic Energy Project, School of Medicine, University of California, Los Angeles, California

SOME INTEREST has been displayed, recently, in a proposed relationship between phenomena observed in radiobiological experiments and the chemical changes that often accompany exposure of aqueous solutions to high-energy radiation.

One type of effect which may be of significance is the production of small chemical changes in the side groups along the main chain of a protein. Since such changes constitute relatively minor variations in the structure of complex molecules, they may easily escape detection in experiments with proteins. However, their nature may be inferred from data obtained in irradiation studies on solutions of the amino acids which participate in the protein structure, as illustrated by some recent work in which deamination reactions and the formation of aldehydes and hydrogen were described (*1*, *2*). This paper gives results found with the amino acid cysteine.

An explanation for the action of radiation on pure water is fundamental to an understanding of the effects found in aqueous solutions. Since theoretical and experimental work on this subject has been summarized several times (*3–8*), it will be discussed briefly.

Ion pairs (H_2O^+, H_2O^-) are produced by the absorption of radiation quanta or, more frequently, by inelastic collisions between water molecules and the secondary electrons. Dissociation followed by reaction with oxygen leads to formation of the radicals H, OH, and HO_2. Radical interactions near the originating sites cause the formation of hydrogen and hydrogen peroxide, but their concentration is limited by reactions with radicals which have diffused away from the particle tracks.

In oxygen-free water, the situation is appreciably less complex, since the HO_2 radical is not present except possibly in minute amounts toward the end of the exposure.

Substances dissolved in the water which are susceptible to oxidation or reduction may enter into reactions with the radicals or with H_2O_2, according to the following half-equations (*9*)

Reduction

$$OH + H^+ + e \rightarrow H_2O \quad (1)$$
$$HO_2 + 3H^+ + 3e \rightarrow 2H_2O \quad (2)$$
$$H_2O_2 + 2H^+ + 2e \rightarrow 2H_2O \quad (3)$$

Oxidation

$$HO_2 \rightarrow O_2 + H^+ + e \quad (4)$$
$$H \rightarrow H^+ + e \quad (5)$$
$$OH \rightarrow \tfrac{1}{2}O_2 + H^+ + e \quad (6)$$
$$H_2O_2 \rightarrow O_2 + 2H^+ + 2e \quad (7)$$

In basic solution, the formulation of these equations is somewhat different since the HO_2 and the H_2O_2 are largely in the ionized forms O_2^- and HO_2^-.

Experimental

The solutions were made up with a sample of cysteine hydrochloride, from the Nutritional Biochemicals Corporation, which had the composition C 23.23, H 4.74, N 8.01, S 20.97. Its specific rotation (D,25°) was 7.2 in 1*N* HCl and −13.1 in water, compared with published values 7.2 and −10.4. Spectroscopic analysis showed less than 0.003% of iron and copper.

The water for the solutions was specially prepared from laboratory distilled water by further distillation from a solution 0.01*N* in NaOH and 0.01*N* in $KMnO_4$, then from 0.01*N* H_2SO_4 and once additional.

The *p*H was adjusted by the addition of HCl or NaOH without the use of buffers. This method was preferred from the standpoint of exclusion of impurities; and, at any rate, buffering was unnecessary since irradiation caused no *p*H change in these solutions except near *p*H 7, where there was a decrease of about 0.2 unit.

Fresh solutions were prepared immediately prior to each run, and for the most part they were stable for several

*PRESENT ADDRESS: Chicago Midway Laboratories, University of Chicago, Chicago, Illinois.

FIG. 1. Chamber for deaeration of samples to be irradiated

hours. However, at alkaline *p*H and the highest concentration (0.005*N*), there was a small amount of autoxidation during the irradiation period for which a correction was made from data obtained in blank runs.

The chamber in Fig. 1 was used for the preparation of samples to be irradiated after the removal of dissolved air. In it, the samples could be kept under evacuation for several hours without direct pumping, which had the advantage that there was only a small loss of solvent. The solutions were introduced into the larger bulbs and a connection made at the spherical joint to a 5-liter ballast flask, that was pumped out to about 10μ with a Megavac pump. After evacuation, the stopcock to the deaeration chamber was opened with the line to the pump closed and the solution left in contact with the evacuated space for one half-hour while being stirred with a small magnetic stirrer. This cycle was repeated ten times. Then the chamber was disconnected at the spherical joint and the solution passed into the smaller bulb, which was sealed off at a constriction.

The samples were exposed bilaterally to unfiltered X-radiation at a rate of about 1,000 r/min from two 250-kvp Picker therapy heads operated in apposition. The spectral distribution of the radiant energy from this source has been described by Greenfield (*10*). The energy absorbed by the solutions was estimated by following the decrease in Fe^{++} concentration in a dilute solution of ferrous ammonium sulfate in 0.8*N* sulfuric acid exposed under the same conditions (*11*).

For ion-pair formation in air by electrons of moderate energy, the energy loss, *W*, is generally accepted as 32.5 ev (*12*). The absence of similar data for aqueous media has caused a lack of uniformity in the reporting of chemical data by different authors.

Some have assumed that the *W*-values for air and water are the same and have given results in terms of the amount of chemical change per ionization, the ionic yield. Others have preferred to avoid this assumption and to use, instead, the *G*-values, which give the number of molecules transformed for the absorption of 100 ev.

Still a third method is to report the 32.5-ev yield, but without explicit association of this quantity with an ionization. The last system is used here, the yield being taken as the number of molecular equivalents formed or destroyed in the test solution when 6.3 atoms of Fe^{++} are oxidized in the dosimeter solution.

Results

Albert first worked with cysteine in an attempt to initiate the chain reaction between hydrogen peroxide, cysteine, and aminoacridine (*13*) through the agency of ionizing radiation. The results did not appear promising, and this project was abandoned in favor of a study of the action on cysteine alone.

A collection of data was obtained for the disappearance of the thiol group and for the formation of hydrogen peroxide and hydrogen sulfide in solutions irradiated for the most part with a dose of 20,000 roentgens. The dependence of the yields for these reactions on *p*H, concentration, and presence of dissolved air is shown in Figs. 2–4. The yields for thiol loss, peroxide formation, and sulfide forma-

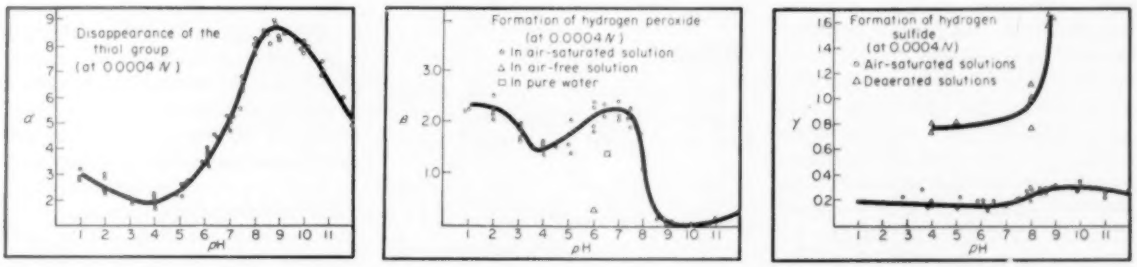

FIG. 2. Dependence of reaction yields of cysteine irradiation on pH

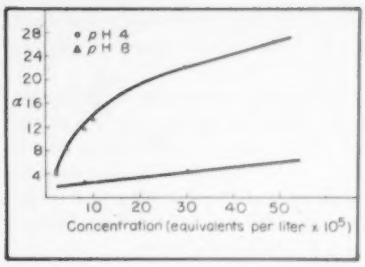

FIG. 3. Effect of concentration on thiol loss

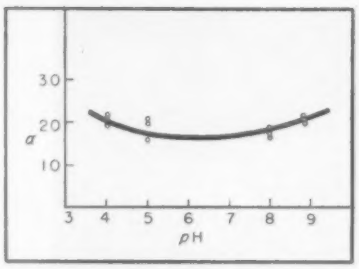

FIG. 4. Cysteine oxidation in deaerated solution (at 0.0004N)

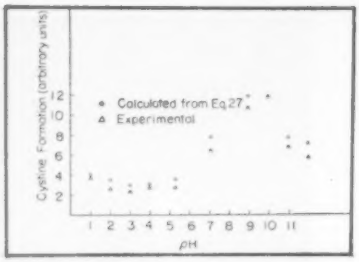

FIG. 5. Cystine formation (20,000 r, 0.0004N)

tion are designated, respectively, by α, β, and γ.

Some conclusions regarding the main course of the radiochemical reaction could be inferred by comparison of the amount of cystine formed in the irradiated solutions, as determined analytically, with values calculated from the disappearance of cysteine (Figs. 5 and 6).

The experimental results were not highly reproducible. For thiol disappearance (at 0.0002*N*), doses of 5,000 r induced concentration changes in the range 0.11–0.17 (equiv./1) $\times$ 10^4; 40,000 r caused changes of 0.91–1.03 (equiv./1) $\times$ 10^4. The yields for hydrogen peroxide and hydrogen sulfide were somewhat more erratic, as is evident from the point scattering in Fig. 2. Detailed experimental data are given elsewhere (*14*, *15*).

Analysis

Suitable methods of analysis for the determination of radiochemical changes are sometimes hard to find, particularly for organic compounds, since it is usually necessary to work with dilute solutions in the range 10^{-3}–$10^{-5}M$ and to detect concentration changes of the order 10^{-4}–10^{-6}. Colorimetric methods are convenient when applicable, and in the present work it was possible to use such methods exclusively.

The colorimetric analysis for Fe^{++} (dosimeter solution) was made with *o*-phenanthroline (*16*); for cysteine, with the Folin and Looney phosphotungstic acid reagent (*17–19*); for cystine, with the Folin reagent plus sulfite (*20–22*); for hydrogen peroxide, with the Bonet-Maury titanium sulfate reagent (*23*, *24*); and for hydrogen sulfide, with *p*-amino dimethylaniline plus Fe^{+++} (*25*, *26*). The approximate molecular extinction coefficients for these reactions are 11,000 (5,100 Å), 4,200 (7,400 Å), 8,200 (7,400 Å), 560 (4,040 Å), and 17,000 (7,500 Å). Optical densities were measured with a model DU Beckman spectrophotometer using 1-cm Corex cells.

Concentrations in the irradiated solutions were determined by relating the optical density measurements to a set of reference curves prepared from solutions for which the composition was known. The peroxide and sulfide reference curves were made up using diluted samples of solutions standardized in the usual way, while the data for the iron and the amino acid curves were obtained in solutions made up by weight. The cysteine curve, based on phosphotungstic acid, was more firmly established by corroboration with the ferricyanide method of Mason (*27*). Rather careful adherence to a standardized working schedule is essential in these colorimetric analyses, since the color development depends on a reaction rate (*17*, *18*).

With one exception, the reagents were specific for the compounds for which they were intended and were unaffected by the other substances present in the solution. The exception was the phosphotungstic acid, which gave some color with hydrogen sulfide, but the amounts of the latter were so small that its effect was negligible, except in deaerated solution where a correction was applied to the cysteine data. All the reagents were inert toward cystine disulfoxide and cysteine sulfinic acid.

Discussion

The formation of hydrogen sulfide indicated that the disappearance of the thiol group might be explained as

$$RSH \rightarrow H_2S \rightarrow S \qquad (8)$$

$$RSH \rightarrow RSSR \rightarrow \text{Higher oxidation products} \qquad (9)$$

The second step in Eq. 8 is the oxidation reaction found by Loiseleur (*28*).

The amounts of hydrogen sulfide present in the solutions at the end of the exposure were not enough to account for the change in thiol concentration. Hence, if Eq. 8 represented the main course of the reaction, it would have to be postulated that the H_2S found was only a fraction of that formed during the irradiation. This appeared improbable due to the inefficiency of the Loiseleur reaction. On the other hand, the reaction in Eq. 9 was reasonable in view of the relative ease with which cystine is oxidized by ordinary chemical agents.

The work of Folin, Lugg, Clarke, and others (*17*, *19*, *20*, *21*) on the reactions of phosphotungstic acid with cysteine and cystine suggested a method for developing evidence on this question. They showed that cystine was inert toward phosphotungstic reagent, but that cysteine reduced it with the formation of a blue color equal in density to that produced by an equivalent amount of hydrogen. In the presence of sulfite, the cystine was no longer inert but developed a color with an intensity the same as an equimolar concentration of cysteine. Under the same conditions, the color density for cysteine increased by a factor which was shown to be theoretically 2. We have checked this experimentally and found the value 1.95 as the average of about thirty determinations.

Hence, if one starts with a solution of cysteine and progressively changes a part of it into cystine so that a series of solutions are formed which contain increasing amounts of cystine, optical density in the presence of sulfite and phosphotungstic acid would vary as

$$\text{O.D. due to cysteine} = 1.95\, d_0\,(1 - \epsilon) \qquad (10)$$

$$\text{O.D. due to cystine} = 0.97\, d_0 \epsilon \qquad (11)$$

$$\text{O.D. total} = 1.95\, d_0\,(1 - \epsilon/2) \quad (12)$$

where d_0 is the O.D. of the original cysteine solution without sulfite and ϵ is the fraction of the cysteine converted. These formulas agree quite well with optical density data obtained using mixtures of known composition.

The agreement between the calculated and experimental data of Fig. 5 shows that, for this case, practically all the cysteine lost from the test solutions reappeared as cystine. However, under prolonged exposure, the experimental values became less than the calculated (Fig. 6). This indicated that, as the concentration of the cystine built up, it was itself attacked.

Additional confirmation for this point of view came from a study of the radiooxidation of cystine reported previously (*29*), although its oxidation products could not be identified due to the lack of suitable methods of analysis. Two-dimensional paper chromatograms run for this purpose were inconclusive.

In assaying the results, it is convenient to consider the yields as if they were derived from one ionization, although, as shown earlier, this may not be completely realistic due to the uncertainty in the value of W. But if this assumption is made, it follows that the yields will be determined by reaction of the solute with the radicals H, OH, and HO_2, which come from one ionization. In many cases they are of the order of one. Here, however, the yields were consistently higher, and to explain them, it seems necessary to postulate either another source of radicals (from dissociation of excited solvent molecules) or some sort of chain mechanism.

Effect of *p*H. As the *p*H was increased starting from 1 (at 0.0004*N*), α first decreased from a value of about 3 to a minimum of 1.8 around *p*H 3.8, then rose to a maximum of 8.7 near *p*H 9. This variation was associated with the presence of oxygen rather than with changes in the zwitterionic character of the amino acid or with ionization of the thiol group, since the reaction showed little dependence on *p*H in deaerated solutions. The importance of oxygen may at first seem unreasonable until it is remembered that its concentration is nearly the same as that of the solute in these dilute solutions. α was also quite sensitive to concentration and increased to a value of 26 at 0.005*N* and *p*H 9.

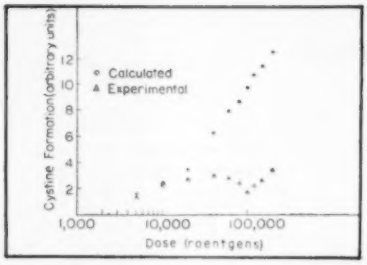

FIG. 6. Cystine formation vs dose (0.0004*N*, pH 5.4)

In the same solutions, β began at 2.3, dropped to 1.45, then rose to 2.3 at about *p*H 7, and finally fell to a level that was barely detectable with the titanium sulfate reagent; γ was in the range 0.2–0.3 and was fairly independent of the *p*H.

Peroxide formation. The formation of peroxide was reduced to a low level (but not zero) by the removal of air, and it was considerably greater in the presence of cysteine than in pure water. The cysteine and peroxide were stable together for several hours in acid solution, which gave further evidence that radiochemical changes cannot in general be explained solely on the basis of reactions with hydrogen peroxide. In alkaline solution, some peroxide may also have been formed, but it could have there only a transient existence because of its rapid reaction with cysteine at elevated *p*H.

The results are consistent with the view that the OH radicals are used up for the most part in oxidation of the cysteine, while the H atoms form either hydrogen sulfide or hydroperoxyl radicals. The latter then give hydrogen peroxide, which may also react with cysteine at alkaline *p*H. But there is no combination of these reactions, if operative on a stoichiometric basis, which is sufficient to explain adequately the high yields found.

It is of interest to compare the data given here with some figures reported by Barron (*30*) and Kinsey (*31*) for the tripeptide, glutathione. We are in fair agreement with the work of Barron, who used the ferricyanide method, over the range which he covered. The complication introduced by the use of buffers is clearly shown in his paper. The work of Kinsey is somewhat more difficult to interpret due to the method of analysis used. Cyanide was first added to reduce the oxidized glutathione, followed by a titration with iodate. A question arises here, since cyanide will restore only one-half of the glutathione, except in strong alkali; and also it has been found that the cyanide is not completely inert toward potassium iodate. Accordingly, somewhat more work along these lines may be desirable. Neither of these papers gave any report on the formation of peroxide or sulfide, but a recent publication by Dale (*32*) presented a rather extensive study of the factors affecting the formation of sulfide. Again we are in fair agreement, except for the data in air-free solutions.

* * *

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A continuous-flow liquid monitor, designed for measuring α-β-γ-activity in water, detects Sr^{89} at 3×10^{-6} $\mu c/cm^3$. A unit for calibrating the monitor G-M tube can be used for static measurements with a sensitivity of 1×10^{-6} $\mu c/cm^3$ Sr^{89}

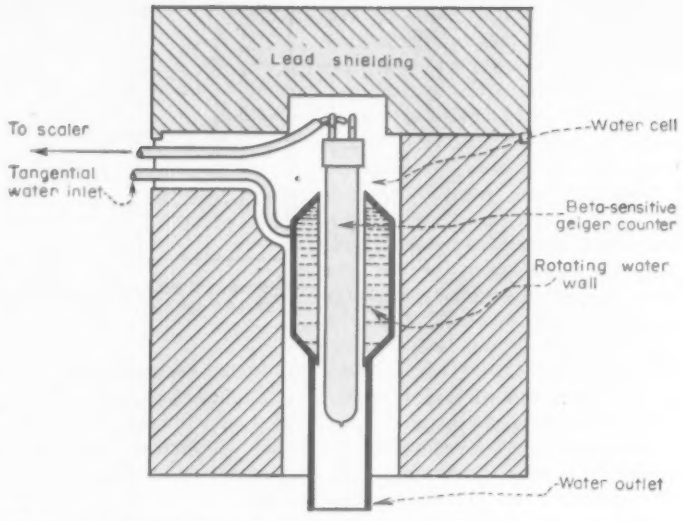

FIG. 1. Cross-section view of continuous-flow water monitor

Monitoring of Liquids

By W. M. HURST*
Oak Ridge National Laboratory
Oak Ridge, Tennessee

A CONTINUOUS-FLOW radiation monitor and a calibration unit were developed primarily for detecting contamination of drinking water. However, other applications might include measurement of: naturally occurring unstable isotopes in excreted or contained body fluids of the human being, radioactive gas concentrations, activity of a solid upon the inner surface of a cylinder, and the rate of plating out of activity from a solution.

The sensitivities of the monitor and the calibration unit, 3×10^{-6} and 1×10^{-6} $\mu c/cm^3$ for Sr^{89} in water, well satisfy the provisional level for drinking-water contamination (8×10^{-6} $\mu c/cm^3$) established by the National Committee on Radiation Protection of the National Bureau of Standards.†

The radioactivity level of some natural water sources is readily measurable due to the leaching out of the unstable isotopes near the earth's surface (*1*). A more practical problem relates to the operation of large nuclear reactors and the chemical processing of radioisotopes, where careful measurements are made of effluent to guard against discharge of excessive radioactive materials. It is thus feasible to consider operation of a continuous-flow monitor to alarm at the level assigned for short-term ingestion, and to concentrate a sample of drinking water at appropriate intervals for the long-term ingestion low-level measurements.

Description of Monitor

The continuous-flow water monitor, consisting of water cell, radiation detector, and lead shielding assembly, is shown in Fig. 1. The water cell surrounds the radiation counter with a wall of water. The only beta absorber between the water wall and the sensitive region of the counter are a $\frac{3}{16}$-in.-thick annular air gap and the counter wall.

Water is continuously injected at a tangent into a stationary flanged cylinder. The injected stream of water becomes a rotating cylindrical wall of water of increasing volume and decreasing inside diameter, until the inside diameter of the water outlet in the lower flange is reached and equilibrium is established. The inside diameter of the upper flange, where the beta-gamma counter is inserted, is smaller than the water outlet to prevent spill-over.

For a water cell of the dimensions given in Fig. 2, a water flow of 4 liters/min (20-psi water inlet pressure) is required to maintain a wall of water of 11-mm radial thickness. Regulation of the water flow is not critical—the counter wall is not touched by the water wall regardless of how slowly or rapidly the water flow is established.

Water Cell

The design problem is one of continuously injecting water into a rotating cylindrical wall of water without causing turbulence.

A circular jet introduces considerable turbulence in the water wall. A slit jet (Fig. 2), made by partial flattening of the water inlet tube, provided a considerable improvement. The remaining amount of turbulence was largely eliminated by having a uni-

* PRESENT ADDRESS: Balcones Research Center, University of Texas, Austin, Texas.
† More recent data is available in NBS Handbook 52 (March '53).

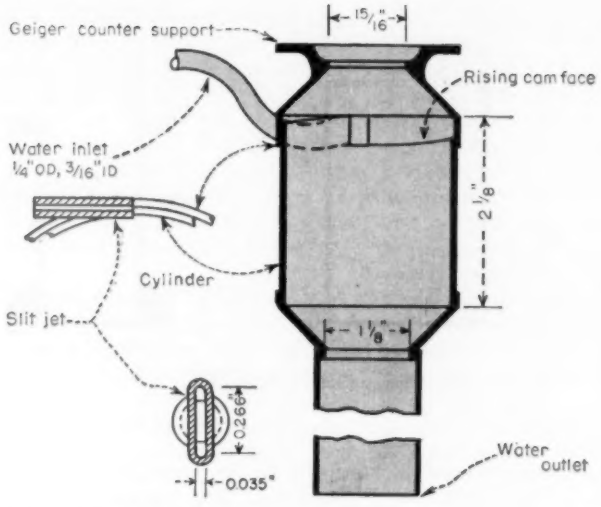

FIG. 2. Water cell, with details of slit jet

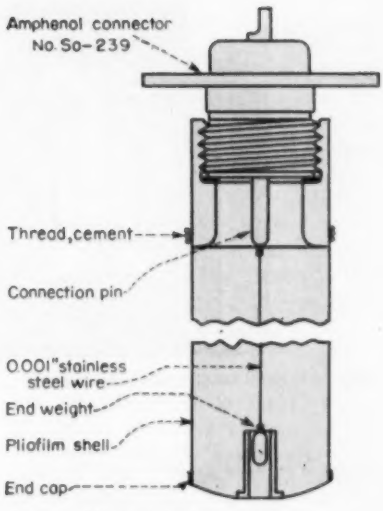

FIG. 3. ORNL alpha-beta counter

for Radioactivity

formly rising cam face formed on one end of the cylinder, and subtending the slit-jet height over one revolution of the cylinder. The jet stream is thereby introduced, not at a point, but throughout one revolution of the rotating water wall.

Cell-wall material. The choice of material for the water cell depends upon several factors, including the *p*H value, the isotopes involved, and the level of activity in the water. The removal of radioisotopes by plating out onto the cell wall is increased if the water cell is metallic or if the water *p*H value is approximately 7. However, it is of no practical significance for monitoring drinking water, where the level of activity is usually less than about 1×10^{-8} $\mu c/cm^3$.

A five-month test to detect plate-out has been made of the ORNL drinking water. Negative results were obtained with brass and polyethylene sample cells. Had radiation been detected on the cell walls, there still would not have been a significant increase in background counting rate unless gamma radiation were present or beta particles of energy greater than about 2.1 Mev.

In practice, the 11-mm water wall is effective shielding for beta emitters of a maximum energy somewhat higher than 2.1 Mev, since the majority of betas emitted occur at about one-third maximum energy. Where the water flow to be monitored contains a gamma emitter of concentration greater than about 1×10^{-8} $\mu c/cm^3$, the water cell should be made of polyethylene or unplasticized polystyrene.

The rise with time of the background counting rate due to plating out would depend upon the solution *p*H and the amount of gamma-emitting isotopes present and their plating-out characteristics. The addition of several drops of HCl per liter of water, to reduce the *p*H value to less than 2, would be particularly helpful in reducing plate-out.

P^{32} contamination, particularly troublesome in this respect, is difficult to remove from the cell wall.

Radiation Detector

The choice of a radiation detector is influenced by the energy spectrum of the unstable isotopes.

High-energy detector. If the activity includes mixed fission products or a significant percentage of beta emitters of about 0.7-Mev maximum or higher, the detector suggested is a thin-wall G-M counter, such as the Radiation Counter Laboratory Mark 1, Model 11. Such a counter, having a wall of about 30 mg/cm², detects incident beta particles of energy greater than about 0.16 Mev, and in practice is useful where the maximum energy of the beta particle is 0.5 Mev or higher. The background counting rate of the shielded counter is about 35 cpm.

Low-energy detector. Where detection of beta particles of less than about 0.7-Mev maximum energy, or alpha particles, is required, an alpha-beta counter (ORNL drawing D-9638) sensitive to incident betas of about 20-kev energy or higher is used. This is a cylindrical Geiger counter (Fig. 3) with a 0.0002-in.-thick wall (less than 0.7 mg/cm²) of rubber hydrochloride (Pliofilm). The counter is continuously flushed with 10% methane-90% argon counting gas at a flow rate of about 10 cm³/min; other gases more suitable for operation in the Geiger region could be chosen. The gas flow and pressure required to eliminate air

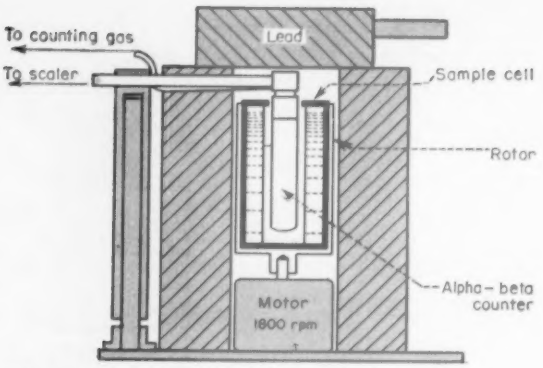

FIG. 4. Liquid-sample calibration unit

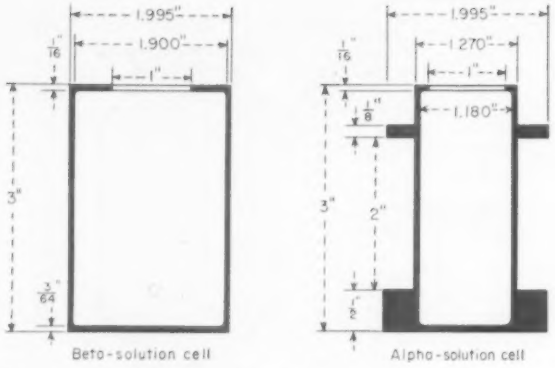

FIG. 5. Calibration-unit sample cells

from the counter depend upon the size and number of pin holes found in such thin rubber hydrochloride. Since the inner surface of the shell is coated with a transparent film of gold (50 $\mu g/cm^2$) for electrical conductivity, the counter is photosensitive and must be shielded from light. The shell is rugged and may be collapsed without injury. The Geiger-region plateau is 1.95–2.2 kv at ~150 cpm. The sensitive region of the counter is about 1 in. long at 750 cpm with a $Sr^{90} + Y^{90}$ source. The background counting rate of the counter, when shielded with 3 in. of lead and the water wall, is approximately 10 cpm; the useful beta window area is about 3.5 in^2.

Gas-flow control. Operation of the beta counter requires a flow of counting gas at about 2-mm-Hg differential pressure. In practice, a gas flow of about 10 cm^3/min is adequate; this may be reduced if the counter shell is sufficiently gas-tight.

The gas flow is metered with an oil manometer measuring the pressure drop across an impedance formed by a 10-in. length of 0.031-in. inside diameter stainless-steel tube. A gas bubbler may result in spurious counts due to pulsing of the counter shell. A pressure-limiting device is formed by an inverted tube which permits gas to escape if the pressure rises above 5-mm Hg.

Mechanical vacuum-pump oil is used to avoid undesirable vapors. Fabrication of the gas control and some other parts must include careful internal cleaning followed by baking in a vacuum oven to remove water which seriously affects the characteristics of the counting gas.

When pressure is first applied to the system, the connections between the gas-flow controls, the gas-supply tank, and the alpha-beta counter should be made cautiously after preliminary adjustments of the tank and regulator valves, to avoid blowing oil out or injuring the counter shell.

Calibration Unit

The calibration unit (Fig. 4) is used to measure the response of a radiation detector to solutions of known activities and various maximum energies, with a geometry closely approximating that of the continuous-flow water cell and detector assembly. The response, in cpm, is plotted as a function of the radiation energy and activity, giving a graph of the sensitivity and energy dependence of the system.

Sample cell. The configuration of the continuous-flow water cell and radiation detector is closely duplicated by an 80-cm^3 liquid sample in a flanged sample cell of 131-cm^3 total capacity, placed in a hollow rotor fixed to an 1,800-rpm motor shaft. Centrifugal force forms a vertical water wall of about 1-cm radial thickness, leaving an air space into which the alpha-beta counter is lowered. Where solutions of alpha radiation or low-energy beta particles are to be measured, a small-volume cell is used (Fig. 5).

Detector sensitivity. The beta-energy dependence and sensitivity graph, shown in Fig. 6, is for the ORNL alpha-beta counter (Fig. 3). The net counting rate is a linear function of the maximum beta energy between about 0.9 and 2.3 Mev.

The response of the RCL Model 11 G-M tube was determined under substantially the same conditions. A temporary setup was used to accommodate the increased length of the commercial tube; it is not described here since that tube would normally be used only in the continuous-flow unit.

Liquid-sample measurements. In practice, the calibration instrument is also useful for measuring radioactive liquid samples, of 15–80 cm^3, where it is desirable to assess quickly the approximate activity of fluids. Where the identity of the unstable isotope is known, measurements of activity may be made between the approximate limits of 1×10^{-6} and 1×10^{-2} $\mu c/cm^3$, depending somewhat upon the energy of the particles.

If the calibration unit is also calibrated with an absorber (for instance, a Lucite cylinder of 0.015-in. wall thickness or 50-mg/cm^2, sliding over the counter shell), a graph of N_1/N_2 plotted against maximum beta energy permits assessing the approximate maximum energy of an unknown emitter.

Experimental Results

The continuous-flow water monitor was operated for several months, attached to a supply of drinking water. The possible contamination of that water supply would likely be by both high- and low-energy beta or gamma emitters. Thus, the RCL Model 11 detector was used.

The Geiger tube was connected to a commercial scaler (scale of 8), which fed into a Streeter-Amet mechanical recorder (Model SCI-4). The recorder printed at 15-min intervals with a recording error not greater than 7 counts/15 min. The maximum integrating and recording error of the system is about 1.3%. The expected variations in the 15-min background

count are within ±12% of the average at the 0.99 confidence level, so it is feasible to calibrate the sensitivity of the monitor in terms of the over-all response at the mechanical recorder. Threshold detection of activity is then a net counting rate equal to 15% of the averaged background, and, for a 1.5-Mev beta emitter such as Sr^{89}, would occur at a concentration of 3×10^{-6} $\mu c/cm^3$.

Where increased sensitivity is required for the detection of alpha particles or low-energy beta radiation, the ORNL alpha-beta-gamma counter is suggested. In general, the application of that counter is logically in the laboratory or equivalent surroundings because it is a continuous gas-flow type.

The hydrogenous gas (10% methane, 90% argon) results in a sensitivity to fast neutrons from a polonium-beryllium source such that a field of 12 $n/cm^2/sec$ gives a net counting rate of 40 cpm. A field of 1 $n/cm^2/sec$ is detectable and would result in an assumed beta concentration.

A radium source (0.18 mg in ½-mm platinum wall) at 50-cm distance gave a net counting rate of 32 cpm. The radium source at 50-cm distance, using the RCL tube, gave a net counting rate of 30 cpm. The values cited are for the detectors in the 3-in.-thick lead-wall shield in normal operation.

The minimum amount of solution activity detectable is determined by the variations in the background counting rate. Radiation sources influencing the background count include: radiochemical processing and reactor gaseous discharge, portable or transportable sources used in laboratory work, and the transporting of waste products. The monitor should be located at a considerable distance from an uncontrolled thoroughfare, and up-wind from radioactive gas discharges. As the wind direction does vary, large distances are desirable where a reactor site is involved.

Potassium-40 measurements. Exposure of the human being to the principal natural radiation sources (cosmic rays, U-Th-Ac isotope series, Ra, K^{40}) is assessed at 0.6 mrem/day (*2*). K^{40} is of particular interest because, as a fixed-percentage component of natural potassium (*3*), it is present in such body fluids as blood and urine and is available for test measurements by the liquid-monitoring apparatus.

The concentration of potassium in blood or urine is approximately 2 mg/gm (*4*, *5*). Water solutions containing 2 and 10 mg/cm^3 of K were measured in the calibration unit, giving net counting rates of 5.4 ± 0.7 cpm and 28.4 ± 1.6 cpm, respectively. The response of the instrument is then approximately 1 cpm, net, per 0.35 mg of K per cm^3, and a solution of 2 mg of K per cm^3 is readily detected. Other measurements were made with body fluids, and the results were in agreement.

Plutonium-239 measurements. A solution of Pu^{239} (in 1*M* HNO_3) was processed and measured for alpha activity by counting in a windowless gas-flow proportional counter. The activity measured was 7,560 dpm/cm^3, or 3.4×10^{-3} $\mu c/cm^3$.

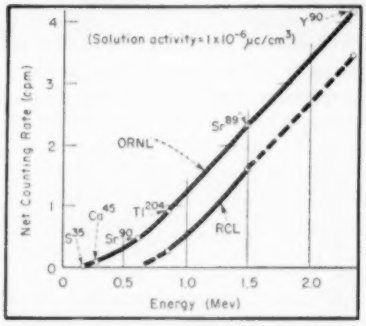

FIG. 6. Energy dependence of RCL and ORNL detectors (determined with calibration unit)

A check was made for beta activity by interposing absorbers between the sample and a beta counter. The net counting rate was zero when the total absorber was 4 mg/cm^2, indicating no significant amount of beta radiation of greater than 50-kev energy.

A measurement was made of the Pu^{239} solution with the calibration unit, using the alpha solution cell (Fig. 5). The counter was operated in the Geiger region, because a constant collector voltage is contemplated for the continuous-flow water monitor. The alpha-solution activity measured 260 net cpm.

The response of the calibration unit to 5.15-Mev alpha radiation in a 1.3×10^{-5} $\mu c/cm^3$ solution is 1 cpm. The minimu n concentration of 5.15-Mev alpha activity in solution detectable by the calibration unit depends somewhat upon the counting interval. For instance, a 10-min counting interval averaging 13 cpm (3 cpm, net) would indicate the presence of $3.9 \pm 1.2 \times 10^{-5}$ $\mu c/cm^3$ with a 2:1 probability of that value being correct.

A rough calculation relating the alpha concentration and range in water, and the counter geometry, was made as follows:

1. The range of a 5.15-Mev alpha is about 36 mm in air, or 0.0043 cm in water. The annular air gap and the 0.7-mg/cm^2 counter wall are equivalent to 0.85 cm of air, leaving 2.75-cm range in air or 0.0033-cm in water.

2. The counter has a sensitive-region window 6 cm in circumference and 3.7 cm in length, giving an area of 22.2 cm^2. Assuming a mean of the two major axes, the geometry of that window for a point on a 2.6-cm-diameter cylindrical water wall is approximately 35%.

3. Alpha particles penetrating into the sensitive region of the counter would come from a nominal 8.1-cm circumference × 3.7-cm length × 0.0033-cm depth, or 0.1 cm^3, at a 35% geometry. Then the geometry of the counter, related to dpm/cm^3, is 3.5%.

4. Given a solution activity of 7,560 dpm/cm^3, at 3.5% geometry, the calibration unit counting rate should be 264 cpm. The error between the calculated and observed counting rate is about 2%. The assumptions made involve errors such that the close agreement is probably due to several errors cancelling.

* * *

Preliminary objectives of the continuous-flow water monitor to be developed were established in conversations with J. Roberson, former Director of the Office of Research and Medicine, AEC, Oak Ridge, Tennessee, and F. Western, former Associate Director, Health Physics Division, ORNL.

Some of the biological applications and unpublished values for the maximum permissible concentration of some unstable isotopes in drinking water were provided by K. Z. Morgan, Director, Health Physics Division, ORNL, and Chairman of the Subcommittee on Internal Dose, the National Committee on Radiation Protection, National Bureau of Standards. The interest of W. K. Eister and F. C. McCullough, Chemical Technology Division, ORNL, has furthered the instrument's application in the field of monitoring radiochemical process effluents.

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Nuclear Emulsion Techniques for the Measurement of Neutron Energy Spectra

By LOUIS ROSEN
University of California
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

PROCESSING OF EMULSION PLATES and selection of optical plate-scanning equipment were considered in the first part of this article (NU, July, 1953, p. 32). Energy measurements on extended anisotropic neutron sources, such as reactor flux, and measurement of point sources with a nuclear plate detector and hydrogen or deuterium radiator were considered.

We shall now proceed to the oldest and still the most widely used method for neutron spectrum measurements.

Plate as Radiator and Detector

In this case, the photographic plate is used as both radiator and detector, the tracks being due to recoil protons from the H^1 in the emulsion. This method permits one to go to lower neutron energies and lower neutron intensities.*

Although this method has long been used to obtain relative numbers of neutrons as a function of energy, it is only very recently that a serious attempt has been made to deduce absolute values for neutron flux as a function of energy (*3*). It is this problem with which we shall primarily concern ourselves, since the problem of relative energy distributions is but a special case of the problem of absolute energy distributions. [Barschall, Rosen, Taschek, and Williams (*81*) have discussed the difficulties inherent in making absolute monoenergetic-neutron flux measurements by this method.]

Plate exposure. To carry out a neutron-spectrum determination using the nuclear emulsion as both radiator and detector, one exposes the photographic plate, in good geometry, to the neutron flux to be analyzed. The source of neutrons is approximately in the plane of the emulsion, the long plate axis making a small angle with the direction of the neutron beam. Figure 5† shows the geometry for such an experiment, and Fig. 6‡ is a photomicrograph of a typical track produced by an H^1 nucleus that suffered a direct hit by a 14-Mev neutron.

The plate is wrapped in black paper with a thin sheet of platinum separating the emulsion from the paper. The thin platinum shield prevents recoil protons in the paper from passing into the emulsion and producing tracks, which, although eliminated in the analysis of the plate, would add nothing except further complications to an already difficult task.

Plate analysis. The plate analysis is generally carried out in one of two ways. The usual procedure is to measure the projected length (R_p in Fig. 2) of each track which originates within a defined volume of the plate, proceeds within the bounds of a rectangular pyramid of given half angles θ and ϕ, and ends within the emulsion. The axis of the pyramid of acceptance is taken parallel to the projection of the incident neutron beam direction on the emulsion surface (OA in Fig. 2). The absolute range (L) of the proton recoils, in the unprocessed emulsion, is determined from $L = R_p/\overline{\cos\psi}$ (see Fig. 2) where

$$\overline{\cos\psi} = \frac{\int_0^{\psi_{max}} 4\cos\psi\cos\psi\, 2\pi\sin\psi\, d\psi}{\int_0^{\psi_{max}} 4\cos\psi\, 2\pi\sin\psi\, d\psi} = \frac{2(\cos^2\psi_{max} + \cos\psi_{max} + 1)}{3(\cos\psi_{max} + 1)} \quad (8)\S$$

and ψ_{max} is defined by

$$\pi\sin^2\psi_{max} = 4\sin\theta_{max}\sin\phi_{max}$$
$$\theta_{max} \cong \phi_{max} \leqq 15 \text{ deg} \quad (9)$$

The energy of the proton recoil is determined from the appropriate range-energy relation. If the data of Bradner *et al.* (*75*) or Rotblat (*76*) are used, one must correct for the difference between wet and dry emulsion when the plate is not exposed in a vacuum. The range-energy relation of Lattes, Fowler, and Cuer (*74*), however, are directly applicable to B1 emulsions,¶ which are at 50% relative humidity. The range in dry emulsion is approximately 3% less than the corresponding range in an emulsion at 50% relative humidity.

The energy, E_n, of the neutron that produced a given proton recoil of energy E_p is now determined from

$$E_n = E_p/\overline{\cos^2\rho}, \quad (10)$$

where $\overline{\cos^2\rho}$ is the average value of the cosine squared of the angle between the incident neutron and recoil-proton directions and is given by

$$\overline{\cos^2\rho} \cong \overline{\cos^2\psi}\cdot\overline{\cos^2\gamma}$$
$$\gamma_{max} \leqq 15 \text{ deg} \quad (11)$$

and γ is the angle that the incident neutron makes with the axis along which the projected lengths of the tracks are measured (usually the long

* At 14 Mev, a neutron flux of approximately 2×10^8/cm² is required to project, within the bounds of a pyramid of half angle 10 deg, 25 tracks/mm² that begin and terminate within an emulsion layer 200μ thick. With radiator and detector, ~15 times this intensity is required to give an equivalent track density on a 200μ emulsion so oriented with respect to a 10 mg/cm² polyethylene radiator as to afford comparable angular resolution.

† Figures 1–4 appeared in Part I of this article (NU, July 1953, p 32).

‡ Photomicrography done by Margaret Gibson.

§ Equations 1–7 appeared in Part I.

¶ B1 and C2 emulsions have very nearly the same composition and stopping power.

A nuclear plate used as radiator and detector allows measurement of low-energy and low-intensity neutron point sources. Applications of the emulsion technique to high-energy sources and inelastic neutron interactions are described in detail

PART TWO

plate axis). $\overline{\cos^2\gamma}$ is given with sufficient accuracy by

$$\frac{\int_0^{\gamma_{max}} \cos^2\gamma\, 2\pi \sin\gamma\, d\gamma}{\int_0^{\gamma_{max}} 2\pi \sin\gamma\, d\gamma} = (1/3)\,(\cos^2\gamma_{max} + \cos\gamma_{max} + 1) \quad (12)$$

Similarly, the average cosine squared of the angle ψ is

$$(1/2)\,(\cos^2\psi_{max} + 1) \quad (13)$$

The approximations implied in Eqs. 8–13 lead to errors of less than 1% in E_n for θ_{max}, ϕ_{max}, and $\gamma_{max} \leqq 15$ deg. For more rigorous equations, see Allred's and Armstrong's "Laboratory Handbook of Nuclear Microscopy" (*82*). The above procedure reduces the data to the form of relative number of protons vs corresponding neutron energy. To make the transformation to relative number of neutrons vs neutron energy, one must still take account of the variation of *n-p* scattering cross section and escape probability with neutron energy.

The alternative method of plate analysis is used when utmost resolution is desired. The same procedure is followed with the exception that, in addition to R_p, θ and $\tan\phi'$ are also measured for each track, and ψ, L, E_p, and E_n are determined for each track. Since the calculations now become quite time-consuming, we have adopted the practice of performing these calculations on an IBM machine (C.P.C., model 2, 605–527) into which is fed an equation for the range-energy curve along with R_p, θ, and $\tan\phi'$.

For dry emulsion the range-energy relation can be represented by

$$E_p = -0.47 + 0.381R^{1/2} + 0.002778R \quad (14)$$

for $0.5 < E_n < 15.0$ Mev. For wet emulsion the range of each track is multiplied by an appropriate constant prior to the application of Eq. 14.

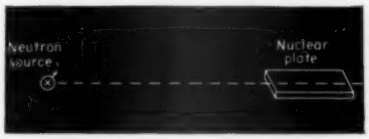

FIG. 5. Source-detector geometry for measuring neutron spectrum from point source using plate as radiator and detector

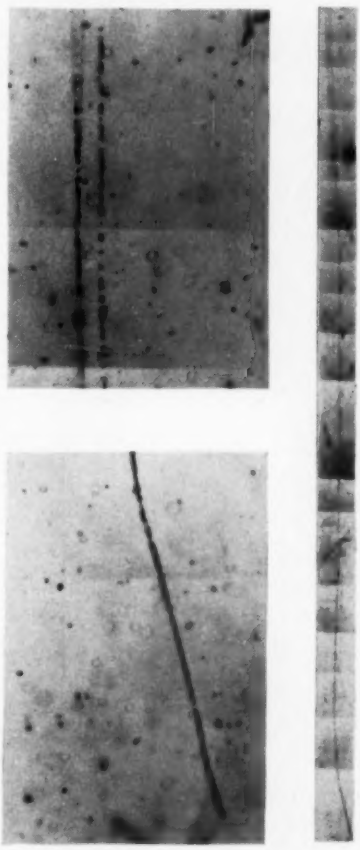

FIG. 6. 1,000μ track in C2 emulsion. At left are first and last 95μ of track

At the two or three energy regions where the fit is off by more than 50 kev, the machine is instructed to make appropriate corrections. For each set of measured quantities (R_p, θ and $\tan\phi'$), the IBM calculates L, E_p, and E_n at the rate of 30 tracks/min. From this point on, the treatment of the data is the same regardless of the method used to analyze the plate.

The flux of neutrons of energy E_n in the energy interval dE_n is given by

$$F(E_n)dE_n = \frac{4\pi N(E_p)dE_p}{4nP(l)\sigma_{n-p}(E_n)\,\overline{\cos\rho}\,V\Theta} \quad (15)$$

where $P(l)$ = probability that a track of given length, l, does not leave the emulsion; n = number of H^1 atoms per unit volume of emulsion; V = emulsion volume analyzed; and Θ = solid angle of acceptance of proton recoils. The remaining symbols are defined as in Eq. 2 (Part I of this article).

It is seen from Eq. 15 that a neutron spectrum measurement on an absolute neutron flux scale implies a precise evaluation of n, V, Θ, and $P(l)$. We shall consider each of these factors.

Hydrogen atom concentration. The evaluation of n is complicated by its dependence upon the water content of the emulsion and hence upon the relative humidity. Ilford Ltd. give a value of 0.056 gm/cm³ of H^1 in C2 emulsions at 50% R. H. and normal room temperature. From this value and from Ilford's data on the variation of moisture content and density with relative humidity, the values in Table 2 are obtained for hydrogen concentration as a function of R. H.

An independent determination of H^1 concentration at 30% R. H. and normal room temperature has been carried out by Dr. A. R. Ronzio. The value obtained by him is 0.053 gm/cm³ ±

5%. This is considered to be in good agreement with the above table. The volume of emulsion analyzed is determined from the plate area scanned and the unprocessed emulsion thickness. The thickness is measured by removing the emulsion from one or more corners of the glass plate backing and using a dial indicator to obtain readings of glass plus emulsion plus cover glass. The cover glass is used between the dial-indicator finger and the emulsion to prevent depressions in the emulsion at the point of contact.

Solid angle of acceptance. The accurate delineation of Θ involves the measurement of angles in two perpendicular planes which we shall call the horizontal angle and the dip angle.

As previously noted, the horizontal angle is precisely and easily defined by using an eyepiece protractor or an eyepiece graticule. To delimit accurately the dip angle, one uses the above measurement of the unprocessed emulsion thickness along with a measurement of the processed emulsion thickness in terms of the fine-focus screw readings of the same microscope which is to be used to analyze the plate. These two measurements determine the unprocessed emulsion thickness corresponding to one division (arbitrary units) on the drum which activates the fine-focus screw.

For angles of $\phi < 25$ deg, the emulsion shrinkage produces a linear transformation in the depth coordinate of any point in the emulsion. Thus, the above procedure immediately permits the delineation of a dip angle of acceptance with respect to the unprocessed emulsion in terms of the fine-focus screw motion per unit projected length of track. The measurement of this angle is then independent of the emulsion shrinkage factor and the calibration of the graduation on the fine-focus adjustment drum. It is only necessary that the fine-focus screw motion be a linear function of the resultant stage motion within the region in which it is used. For small angles (<15 deg), Θ is given with adequate precision by $4 \times \theta \times \phi$, where θ and ϕ are the horizontal and dip angles in radians and refer to the unprocessed emulsion.

TABLE 2—H^1 vs R.H. in C2 Emulsions

Emulsion condition (% *R. H.*)	H^1 *content* (gm/cm^3)
0	0.052
32	0.054
50	0.056
58	0.056
84	0.062

The precision with which ϕ can be determined is improved by inhibiting contraction of the emulsion during processing. This implies a replacement of the AgBr, which is removed during fixation, by some other substance. This can be accomplished by soaking the emulsion, immediately after processing, in an aqueous solution of glycerine. Although the plates must then be analyzed at constant relative humidity, because of the hygroscopic property of glycerine, significant improvement in the determination of Θ and in energy resolution, especially at low energies, can be realized.

Figure 7* shows the energy distribution of two nearly monoenergetic groups of neutrons as measured with soaked and unsoaked emulsions. Although little difference in resolution can be seen at 4.8 Mev, a marked difference can be detected at 1.5 Mev.

Tracks leaving emulsion. $P(l)$, the correction for tracks leaving the emulsion, may be simply deduced from the following considerations on the assumption that the tracks are rectilinear.

In Fig. 8, let t again be the thickness of the processed emulsion, and let ϕ' and L_p denote the same quantities as in Figure 2. It is apparent that for $L_p \sin \phi' \geq t$, the probability, $P(l)$, for tracks within an acceptance dip angle of ϕ' ending in the emulsion is $t/(2L_p \sin \phi')$. The additional assumption being made here is that n-p scattering is isotropic in the laboratory system over the angle ϕ, i. e., $\cos \phi \cong 1$. For the case of $L_p \sin \phi' \leq t$, let us imagine t divided into a number of segments, each segment of length r, where $r = (L_p \sin \phi')/2$.

Now since the average displacement in the vertical plane of the end of a track relative to its beginning is $(L_p \sin \phi')/2$, it is seen that, apart from scattering, all tracks of length L_p and dip angle $\leq \phi'$ that start between a and d and are directed downwards will end within the emulsion volume. It is also apparent that, while most such tracks starting between d and e will also end within the emulsion, some will penetrate the bottom of the emulsion. On the other hand, corresponding to the fraction of tracks starting between d and e and leaving the emulsion, there is an equal fraction of tracks starting below e which remain in the emulsion. That is, the region below e compensates for those tracks which originate in the region between d and e and leave the emulsion. It is therefore apparent that for $L_p \sin \phi' \leq t$, the probability for tracks leaving the emulsion is $(L_p \sin \phi')/2t$ and $P(l) = 1 - (L_p \sin \phi')/2t$. A more rigorous derivation of these factors is available (*10*).

In using the preceding method of evaluating the probability for tracks

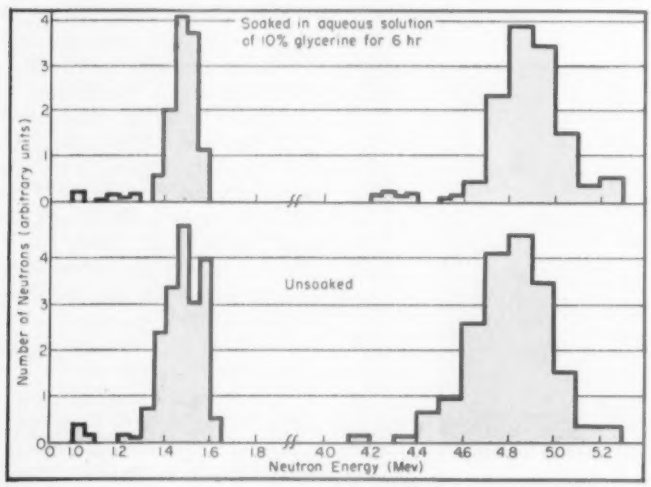
Soaked in aqueous solution of 10% glycerine for 6 hr
Unsoaked
Number of Neutrons (arbitrary units)
Neutron Energy (Mev)
0 10 12 14 16 18 40 42 44 46 48 50 52

FIG. 7. Energy resolution attainable with soaked and unsoaked emulsions

* Plates analyzed by May Bergstresser.

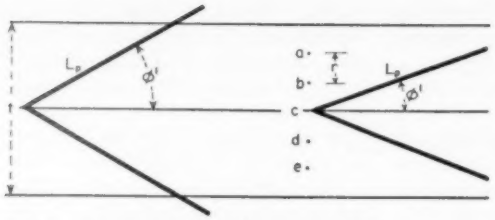

FIG. 8. Geometry for calculating track $P(l)$

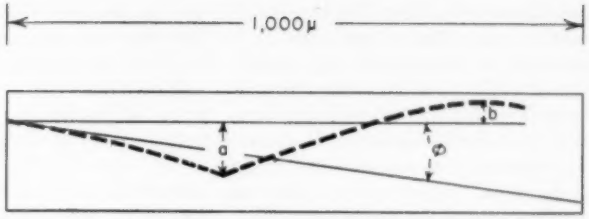

FIG. 9. Profile of 950μ track in vertical plane (200μ-thick emulsion)

leaving the emulsion, one tacitly assumes either that the tracks are rectilinear or that the number of tracks that leave the emulsion due to single and multiple scatterings are equal in number to those that, unscattered, would have left the emulsion, but suffer scattering in such a manner as to remain within the emulsion. Neither of these assumptions is completely valid and both give rise to serious errors when the product of track length and sine of the dip angle of acceptance exceeds $\frac{1}{2}t$.

It is difficult to compute a correction to $P(l)$ even if one assumes only coulomb scattering since tracks may be lost at any point along their trajectories. We therefore use an empirical method of correcting for the escape of tracks from the emulsion. The method adopted is as follows:

The forms of the projections in the plane of the surface of the emulsion (x,y plane) of 100 tracks, each of length 850–950μ, were determined and drawn to scale. The dashed line in Fig. 9 represents the profile, on the emulsion surface, of a track of length 950μ. Now, since the observed changes in direction in the x,y plane occur with equal probability in any plane, we can calculate the fractional loss for a particular category of tracks with reference to a plane normal to the surface of the emulsion.

It can be seen from Fig. 8 that if this track had an initial dip angle of ϕ, the probability that it would end within the emulsion is simply $[t_0 - (a + b)]/t_0$, where t_0 is the unprocessed emulsion thickness. To simulate acceptance dip angles of 10 deg and 15 deg for proton energies of 4, 6, 8, 10, 12, and 13.2 Mev, the beginnings of each section of track (measured from the end of the track) corresponding to the above energies were made to coincide with inclines (both positive and negative) of 2.5, 5, 7.5, and 12.5 deg with respect to the emulsion surface. In other words, observations were made for different track lengths, using the same tracks, but assuming that they originated at the appropriate distance from the end of their ranges. The values of a and b were determined for each incline and for each length of each track. The values of t_0, a, and b were then used to calculate the fraction of tracks represented by each profile and dip angle that would be retained in t_0.

Figure 10 shows the results of our observations for 200μ and 400μ emulsions, respectively, and acceptance angles of 10 and 15 deg in the vertical plane. The dashed lines represent the corresponding fractions of protons that are calculated to leave the emulsion, as a function of proton energy, on the assumption that the protons travel in straight lines, i.e., using the previously obtained expressions for $P(l)$.

It should be pointed out that, although the number of tracks used for the preceding analysis is small, each track represents the trajectory of a proton that has suffered a great many scatterings. Measurements on the trajectories of a relatively small number of protons will therefore yield results that are fairly representative of the results obtainable from a large number of such trajectories.

Emulsion attenuation. It was mentioned earlier in the text that in a given experimental arrangement the plate is aligned so that the target is not precisely in the plane of the emulsion. This is done to prevent the neutrons from traversing large distances of emulsion, since the mean free path of neutrons in emulsion is quite small.

Figure 11 shows the calculated maximum attenuation of a neutron beam as a function of neutron energy and parametric in emulsion thickness traversed. Figure 11 is for Ilford C2 emulsion at 50% relative humidity, the total cross-section compilation of Adair (*79*) being used for these computations. The data given in Fig. 11 may be used to calculate an approximate correction for the selective transmission of neutrons through the emulsion if the average angle that the neutron beam direction makes with the emulsion surface is known.

In practice, it is usually desirable to

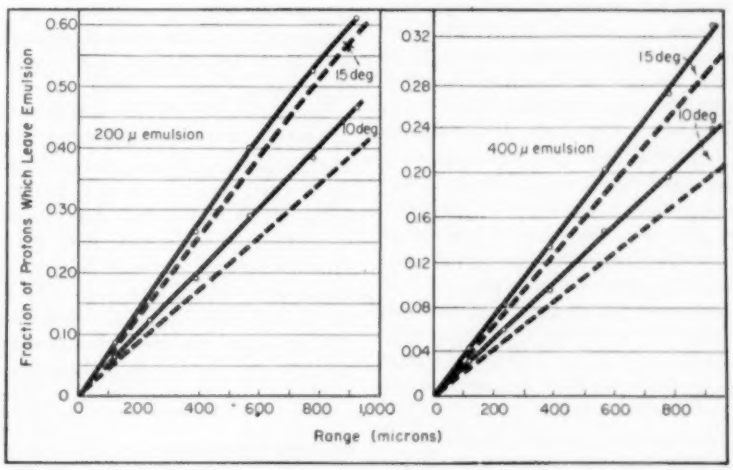

FIG. 10. Corrections for escape of tracks from 200 and 400μ emulsions for acceptance dip angles of 10 and 15 deg

limit the analysis of the plate to a small section nearest the neutron source and thus obviate the necessity for significant corrections due to attenuation of the neutron flux by the emulsion, glass backing, or platinum shield. It should be pointed out that approximately 50% of the total cross section used to calculate the results displayed in Fig. 11 is accounted for by small-angle elastic scattering, which can have little or no effect either on the neutron flux or on the neutron spectrum at a given point in the emulsion.

Inelastic emulsion interactions. When a nuclear emulsion is used as both radiator and detector, the question usually arises as to the abundance of tracks from (n,p), (n,d), (n,t), and (n,α) processes in the heavier elements comprising the emulsion composition, since such tracks would probably be indistinguishable from the tracks caused by protons from elastic collisions between neutrons and H^1 nuclei.

Calculations have been made, on the basis of currently available data, to estimate upper limits for the ratio of the frequency of the projection of protons of energy > 0.5 Mev, into the forward and backward pyramids of half-angle 10 deg, by 14-Mev neutron interactions with each of the elements heavier than H^1, to the frequency of elastic scattering of H^1 nuclei into the same solid angle. The number of confusable protons from (n,p) reactions may represent as much as 15% of the total number of protons recorded from an exposure to a 14-Mev neutron source. However, since the protons from inelastic (n,p) interactions are of relatively low energy because of large negative Q values for many of the reactions, the number of what would appear to be "low energy" neutrons would almost certainly be less than 5% of the deduced number of 14-Mev neutrons.

There is also the possibility that tracks due to low-energy deuterons and tritons from (n,d) and (n,t) reactions, as well as tracks due to low-energy alpha particles, especially from $O^{16}(n,\alpha)$ reactions (*83*), would further add to the low-energy background. However, inclusion of such tracks would probably affect a neutron spectrum in the energy region below 14 Mev by less than 3% of the 14-Mev neutron intensity.

At neutron energies in excess of 10 Mev, one also observes a considerable number of stars from the reaction $C^{12}(n,n')3\alpha$. An example of such a star is seen in Fig. 6. The alpha particles from this reaction, however, should cause no confusion.

Finally one must consider the possibility of tracks due to (a) recoil heavy nuclei and (b) protons knocked on by neutrons that have undergone inelastic or large-angle elastic scattering in the emulsion, glass backing, platinum shield, or paper wrapping.

The maximum energy that a neutron of energy E_n can impart to a nucleus of mass M is $[4M/(1+M)^2]E_n$, and the range of a particle varies inversely as the square of its charge. It therefore becomes apparent that the heavier nuclei in the emulsion will not produce confusable tracks so long as E_n is less than approximately 25 Mev. By varying the parameters indicated in

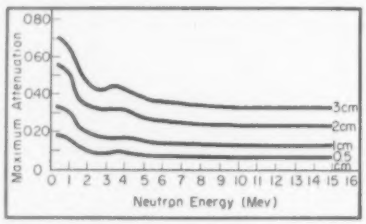

FIG. 11. Maximum attenuation of neutrons by C2 emulsion

(b), it has been shown that, under good experimental conditions (minimum amount of scattering material along path of neutron beam consistent with geometrical considerations), the effect of (b) is essentially negligible.

That these deductions are more or less correct has been established by comparison of neutron-spectra measurements in which the nuclear emulsion is used as both radiator and detector with measurements in which the plate is used only as a detector, a thin layer of paraffin or polyethylene being used as the radiator. These measurements show that, for a primary neutron energy of 14 Mev, a low-energy background of not more than 10% of the primary neutron flux may be ascribed to all of the above factors [i.e., (n,p), (n,d), (n,t), and (n,α) interactions and proton recoils due to neutrons whose energies and/or directions have been altered by processes in the detector].

Energy Resolution

At any given energy the energy resolution attainable is a function of angular resolution, target thickness (when a target is external to the emulsion), and range straggling, which is taken to include the precision with which range measurements are made.

Of these factors, only the first two are amenable to a significant amount of control by the experimenter. It is obviously desirable to keep the target as thin as possible, and the angular resolution as good as possible, since the energy spread induced by target thickness is directly proportional to this thickness while the energy spread due to angular resolution varies directly as $\tan\psi$, where ψ is again the angle between the incident neutron and recoil proton directions, i.e.,

$$E_n = E_p \sec^2 \psi$$
$$dE_n = 2E_n (\tan \psi)\, d\psi \qquad (16)$$

In any given experiment, it is usually the case that intensity and energy considerations pretty well determine the value of the product of target thickness and angular resolution.

At 14 Mev, the best energy resolution attainable with the radiator external to emulsion (Part I), expressed as $\Delta E_n/E_n$ where ΔE_n is the full width at half maximum, is approximately 2% (Fig. 4). If target thickness is chosen proportional to E_n, ΔE_n turns out to be more or less independent of energy in the region 2 Mev $< E_n <$ 16 Mev.

The corresponding values of ΔE_n, with the emulsion as both radiator and detector, are approximately 1.5 times as large. Below 2 Mev, intensity considerations usually preclude the external radiator. In the region of 1.5 Mev, the energy resolution attainable by using the emulsion as both radiator and detector is such that $\Delta E_n \cong 0.3$ Mev (Fig. 7), while at 0.4 Mev $\Delta E_n \cong 0.15$ Mev.

Aside from statistical errors, absolute neutron intensities as a function of energy, i.e., number of neutrons per unit energy interval and per unit solid angle, can be determined (in the region 2–14 Mev) to $\pm 15\%$ by the latter method and to $\pm 7\%$ with the external radiator. The corresponding precisions with which relative neutron intensities *versus* energy can be determined are $\pm 10\%$ and $\pm 5\%$, respectively.

As indicated above, the radiator-detector emulsion does permit measurements down to 0.4 Mev. However, although 0.4-Mev protons can be detected with 100% efficiency, solid-

angle delineation problems prohibit absolute neutron-intensity determinations to better than $\sim \pm 35\%$ in the region 0.4 to 1 Mev. Relative neutron intensity determinations can be made to $\sim \pm 20\%$ in this region.

APPLICATIONS TO SPECTRUM MEASUREMENTS

We shall now consider the application of nuclear plate techniques to two specific problems involving neutron-spectrum measurements.

T(d,n)He^4 Reaction

As soon as the availability of tritium made possible the use of the $T(d,n)He^4$ reaction as a high-intensity source of high-energy neutrons, it was of considerable practical interest to determine whether the neutron spectrum from such a source is indeed monoenergetic or whether excited states of He^4 would be in evidence with resulting emission of lower-energy neutrons. It was also important to determine the Q value (or values) for the above reaction.

The answers to both of these questions could be obtained by an analysis of the neutron spectrum from the subject reaction. To make such an analysis, the external radiator was utilized. The geometry was analogous to that illustrated in Fig. 3, with the single exception that no collimator was used. The axis of the camera made an angle of 90 deg with respect to a singly ionized beam of 200-kev deuterons that was incident on a zirconium-tritium target.

Figure 12* shows the range distribution of the recoil protons as obtained from the photographic detector. The range plotted is the measured projected range divided by the cosine of the angle of projection in the unprocessed emulsion. Emulsion shrinkage was 2.3. To correct more conveniently for straggling and radiator-thickness effects, the extrapolated range was determined from the integral curve and converted into a mean range (*84*). The mean proton range obtained is $1{,}012 \pm 20\mu$, which corresponds, for the emulsion used, to a mean energy (E_p) of 14.0 ± 0.2 Mev.

For small ρ_{max}, as in this experiment, the neutron energy is obtained to adequate precision by increasing the above value of E_p by $\frac{1}{2}E_p\rho^2_{max}$ where ρ_{max} is the angle relative to the neutron direction within which recoil protons are considered for measurement. The neutron energy is thus 14.2 ± 0.2 Mev.

The Q for the reaction, since our angle of observation was 90 deg with respect to the incident deuteron beam and the conditions of "good geometry" were very adequately satisfied (*84*), is

$$Q = \frac{(M_n + M_{He^4})E_n}{M_{He^4}} - \frac{(M_{He^4} - M_{H^2})E_d}{M_{He^4}} = 17.7 \pm 0.3 \text{ Mev} \quad (17)$$

The Q value obtained from the most recent values for the atomic masses of H^2, H^3, He^3, and He^4 is 17.58 Mev.

It is noteworthy that the half width at half maximum of the proton range peak (Fig. 12) is completely accounted for by the straggling term

$$(S^2 + S_m^2 + S_A^2 + S_T^2)^{1/2} \quad (18)$$

where S = range straggling for 14-Mev protons, S_m = apparent range straggling due to errors in measurement (track length determinations in the 14-Mev energy region were considered accurate to 1.5%), S_A = apparent range straggling due to finite angular resolution, and $S_T = \frac{1}{2}$ the emulsion equivalent of the polyethylene radiator.

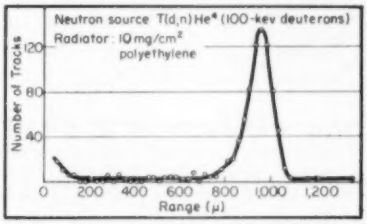

FIG. 12. Recoil-proton range distribution

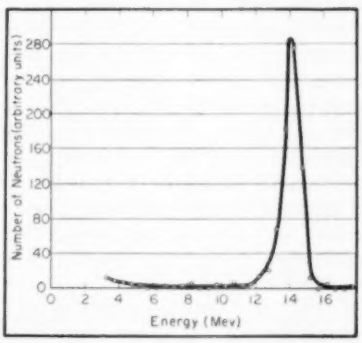

FIG. 13. Neutron spectrum corresponding to proton energy distribution of Fig. 12

The energy distribution of the incident neutrons inferred from the energy distribution of the recoil protons, after making corrections for thickness of radiator,* finite angular resolution, and the variation of the n-p scattering cross section with neutron energy, is given in Fig. 13. It is apparent from this curve, even if it is assumed that all of the neutrons that projected protons into the photographic emulsion were produced by the $T(d,n)He^4$ reaction and proceeded directly from the tritium target to the polyethylene radiator,† that no group of neutrons exists corresponding to an excited state of the alpha particle in the region of 2 to 12 Mev having an intensity greater than 2% of the primary group.

The upper limit of 12 Mev is determined by the thickness of the polyethylene radiator for low-energy neutrons as well as by the maximum neutron energy available. The lower limit of 2 Mev is determined by the resolution of the method. The resolution is in turn determined from the width of the number-vs-energy peak representing the primary neutron group.

It will be noted that these conclusions are well borne out by the more recent data displayed in Fig. 4. These data show no group of neutrons with intensity greater than 1.5% of the primary group and of such energy as to correspond to an excited state of the alpha particle between 1 and 13 Mev.

Inelastic Interactions

As the second example, reference is made to some very recent work on the energy distribution of neutrons resulting from the inelastic interaction of 14-Mev neutrons with various elements. The problem here was to measure the differential cross section with respect to energy for the emission of neutrons when various elements are bombarded by 14-Mev neutrons.

For these experiments, the nuclear emulsion was used as both radiator and detector. Plates were exposed to the neutrons from a 14-Mev neutron

* Plates analyzed by Rexine Booth and Pearl Norwood.

* The correction for radiator thickness was made by adding to each track, before converting to energy, a length (50μ) corresponding to the emulsion equivalent of one half the radiator thickness.

† Many of the low-energy protons were undoubtedly produced by neutrons which arrived at the polyethylene radiator after suffering one or more elastic and/or inelastic scatterings.

source, isolated insofar as possible from all scattering material, and to the same source surrounded by a thin spherical shell of the material under investigation.

Figure 14 shows the results of measurements on approximately 20,000 tracks. The energy distribution of the neutrons from each of the elements investigated, including even Al and C, is approximately Maxwellian up to 4 Mev and can be represented by

$$\sigma(E_0, E_n)dE_n = \text{const. } E_n \exp.(-E_n/T)dE_n \quad (19)$$

where $\sigma(E_0, E_n)$ is the differential cross section with respect to energy for the emission of neutrons of energy E_n when the incident neutron energy is E_0, and T is analogous to a temperature, at an excitation energy E_0, of the residual nucleus.

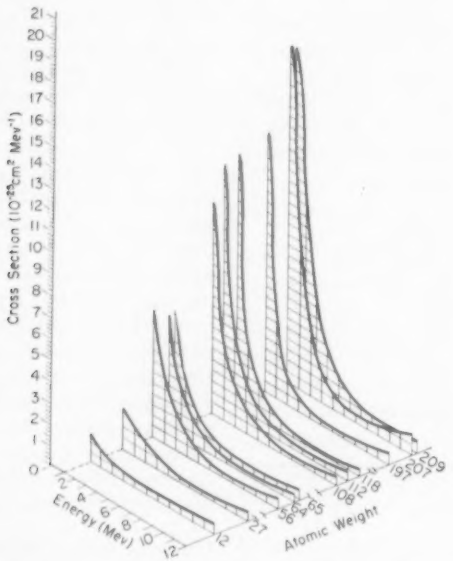

FIG. 14. Neutron-emission cross section vs energy of emitted neutrons for elements bombarded by 14-Mev neutrons

The shape of the energy distributions would seem to give support to the validity of a statistical approach to the interaction of 14-Mev neutrons with nuclei of mass number >50. However, it is noteworthy that the approximate variation of the nuclear temperature (*3*) with mass number, deduced from the measurements represented in Fig. 14 and Eq. 19, is not in agreement with predictions of statistical theories.

The answer to the riddle may lie in the possibility that, although a respectable fraction of neutron interactions in the region of 14 Mev does proceed by way of formation of a true compound nucleus with rapid sharing of energy among all the nucleons and subsequent boiling off of neutrons, a not-negligible fraction of the interactions proceed by way of nucleon-nucleon encounters in which only a few nucleons are involved. The latter mechanism is practically unavoidable if one is to explain the recently observed high cross sections for (n,p) and (n,α) processes.

These applications illustrate two general categories of information readily obtained from precise measurements of neutron spectra.

There is currently considerable theoretical interest (*85*) in the energy and angular distribution of neutrons resulting from the inelastic collision of fast neutrons with heavy nuclei. It is quite possible that such experiments can be carried out with 14-Mev neutrons in much the same way as the experiments of Stelson and Preston (*54*) at 1.9 Mev. Instead of a paraffin collimator, however, one would use a collimator of the type shown in Fig. 3. A target of the element under investigation is placed on the axis of the collimator and at the position now occupied by the center of the camera in Fig. 3. Nuclear emulsions are placed around the target with their long axes in the horizontal plane and on radii that intersect the center of the target. The collimator shields the nuclear emulsions from the direct beam and an additional paraffin shield may be placed behind the collimator and around the detectors in order to shield them from room- and air-scattered neutrons. Experiments along these lines are now being considered at this laboratory.

Such measurements may well prove to be one of the most powerful means at our disposal for probing the nature of nuclear forces and bringing about a better understanding of nuclear structure.

Although at the present time nuclear emulsions offer the best solution to the problem of neutron-spectrum measurements, it should not be assumed that such will always be the case. Plate analysis work is quite arduous and time-consuming (20–60 tracks per hour is about all that one can measure precisely, given a good plate exposed to neutrons of energy not much above 14 Mev). One might hope that a neutron spectrometer, perhaps using proportional counters in coincidence with a crystal from which the pulses are fed into a gated multichannel energy discriminator, could be devised that would compete favorably with photographic emulsions on the basis of accuracy and adaptability.

In considering the advisability of using an electronic spectrometer in a given experiment, however, one must not fail to take account of the fact that nuclear plate methods are in general very economical of accelerator time as well as the time of highly technical people.

* * *

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Hazard Evaluation and Control After a Spill of 40 mg of Radium

It took 3 months of difficult work to clear a building contaminated by 40 mg of Ra. Personnel brought contamination into their homes, and Rn in the air exceeded safe levels for 2 weeks. This article gives the practical experience gained

By R. K. SKOW,
V. V. VANDIVERT, and
F. R. HOLDEN
U. S. Naval Radiological Defense Laboratory
San Francisco, California

AN UNNOTICED SPILL of radioactivity can cause severe contamination of personnel and physical facilities. This was learned recently by the U. S. Naval Radiological Defense Laboratory when it was called upon for assistance after a glass capsule containing 40.3 mg of radium sulfate was unknowingly stepped on in a student laboratory.

Sixteen hours after the spill, USNRDL personnel found widespread contamination of the building and the students' hands, clothing, and personal possessions. Several task forces were immediately created to detect, control, and dispose of the contamination on the students and their property. The building was sealed, and no decontamination procedures were applied until the more urgent problem of contamination of the students was controlled.

Personnel Contamination

The first problem to be worked on was the contamination picked up by the personnel in the laboratory.

Bodies. A number of the students had microgram amounts of radium on the backs and palms of their hands. Routine cleansing and scrubbing with soap and brushes was applied immediately after detection of the contamination, but the cleansing was only partially successful. The hair and legs of the students were also commonly contaminated.

Clothing. The clothing and shoes worn by the students and instructors were heavily contaminated. The soles of shoes, pockets, and lapels commonly had α counts as high as 200,000 dpm.

Personal effects. Such personal property of the students as their automobiles and homes were also heavily contaminated. All surfaces normally touched by hands and feet were affected. It was possible to trace (outline) the footsteps of some of the students into their homes and to follow their movements. A divan was contaminated in the outline of the student's body where he had lain down.

TABLE 1—Radium Contamination of Objects in the Home of One Student

Object	*Alpha activity* (dpm/85 cm²)*
Door knob	1,500
Towel	3,000
Pillow	4,000
Water faucet	125
Bed spread	1,700
Carpet	2,300
Armchair	2,700
Writing desk	3,000
Slippers	275
Chair seat	4,000
Pencil	1,500
Shoes	20,000+
Clothes brush	1,500
Raincoat	4,500

* Measurements were made with a gas-flow proportional counting instrument.

Table 1 gives the data from investigation of one home.

In automobiles, the flooring, foot pedals, and steering wheel were most generally radioactive. Alpha activity on the floor mats was commonly of the order of 20,000 dpm.

Building Contamination

The first entry of the building was made three days after the spill occurred to determine the extent of the contamination and to locate the primary spill for possible recovery of the radium. The survey group wore protective clothing including rubber boots, rubber gloves, cloth hoods, and rescue breathing apparatus (RBA's). The spill was located and marked, and measurements were made of the contamination levels of the air and the surfaces in the room.

The air-borne, long-lived alpha activity measured 1,000 dpm/ft² (maximum permissible concentration for radium is 0.33 dpm/ft²). The air-borne radon activity measured 10,000 dpm/ft³ (maximum permissible concentration for radon is 630 dpm/ft³). Near the spill, the beta-gamma radiation 1 ft from the floor measured 20 mr/hr.

Because of the wide and random distribution of the radium, the extent of areas giving off-scale instrument readings, and a scarcity of instruments, no effort was made to document completely the extent of the contamination. The off-scale readings exceeded 30,000 dpm/85 cm² alpha activity.

Rooms and areas in the building fell

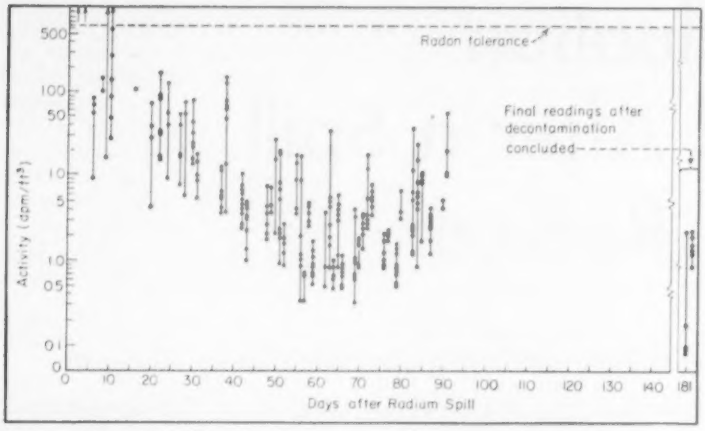

FIG. 1. Effect of building decontamination on air concentration of radon

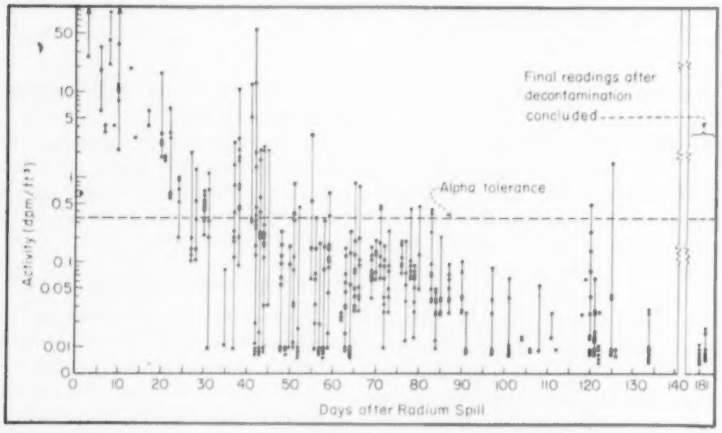

FIG. 2. Effect of building decontamination on air-borne, long-lived alpha hazard

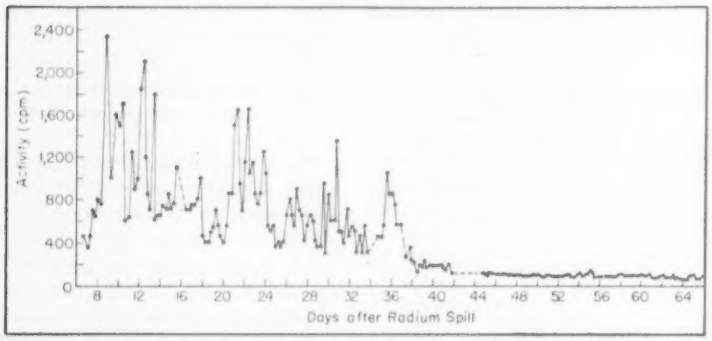

FIG. 3. Record of continuous monitoring of beta activity of radon decay products (collection rate, 1.5 ft³/min)

into four contamination classifications. Twelve rooms, and the halls and stairs, were highly contaminated, eight rooms were moderately contaminated, six rooms were lightly contaminated, and five rooms were clean.

A highly contaminated room was one in which over 20% or the floor gave off-scale readings. A moderately contaminated room was one in which a small number of areas, principally near doors, gave off-scale readings, and the remainder of the room was contaminated to a lesser degree. In a lightly contaminated room, large areas were contaminated significantly, but none were off-scale, and there were some clean areas. Most of the clean rooms were locked at the time of the spill and were not entered after it occurred.

Air Contamination

Throughout all phases of the decontamination work, air analyses were made to measure concentrations of radium, radon, and radon decay products. The samples of particles were collected by a filter paper and radioactivity was measured by a gas-flow proportional counter. Some of the radon analyses were made by the National Bureau of Standards. The majority of the radon concentration estimates were made by calculation of the equilibrium amounts of radon in secular equilibrium with its decay products.*

The data from the air analyses are presented graphically in Figs. 1, 2, and 3. It is noteworthy that the radon concentrations exceeded the maximum permissible concentration (10 $\mu\mu$c/liter, or 630 dpm/ft³) for the first two weeks following the spill. The measurements include the natural atmospheric radon activity, which averages about 2 dpm/ft³, and rarely exceeds 10 dpm/ft³.

During the initial phases of the building recovery operation, all personnel wore rescue breathing apparatus to insure protection from the inhalation hazard. When the radon concentrations fell to safe levels and the radium values approached the maximum permissible concentration, personnel wore standard Navy respirators of the type approved for use against chemical agents.

Personnel Decontamination

The persons, clothing, and effects of the students were treated separately.

Bodies. The students were monitored carefully upon arrival at the decontamination center. All contaminated areas were scrubbed with soap, water, and then citric acid. These methods were partially successful.

Two days after the spill, a team from USNRDL undertook further decontamination (*1*). Alpha contamination was measured before and after each treatment. The treatment consisted of scrubbing with warm decontaminating solution for 2 min, followed by rinsing. The treatment was repeated until no significant further reduction in contamination occurred, usually at levels about 200 to 300 dpm/85 cm².

* A paper describing the techniques employed is being prepared for publication.

The decontaminating solution was an isotonic neutral solution of a complexing agent, a detergent, and a germicide. The approximate composition of the decontaminating solution was 3.0% trisodium citrate, 0.4% commercial detergent, and 0.1% germicide. The solution was applied at *p*H 7 at temperatures from 45° to 50° C.

More recent work (*2*) has shown that complexing agents may produce rapid penetration of the skin barrier of test animals by some radioisotopes. Caution is, therefore, advised in the use of skin decontaminating solutions which contain complexing agents.

Clothing. Wool clothing could not be decontaminated satisfactorily where the contamination levels were high. Vacuum cleaning and dry cleaning were effective only when the original levels did not exceed a few thousand dpm/85 cm^2. Residues of 200 to 300 dpm/85 cm^2 were considered acceptable.

Cotton clothing and other washable fabrics were, in most cases, cleaned adequately by USNRDL standard laundry procedures (*1*).

Shoes were scrubbed with the skin decontaminating solution previously described. Repeated use of this solution gave uniformly successful results.

Personal effects. Floor mats, seat covers, and other similar permeable materials could not be satisfactorily decontaminated and, in most instances, they were discarded as radioactive waste. Hard surfaces, such as steering wheels, were cleaned by repeated use of the skin decontaminating solution.

Floors in the homes were cleaned by the repeated use of surface abrading agents, detergents, and vacuum cleaning.

Building Decontamination

The immediate objective of decontamination of the building was to remove as large a portion of the spilled radium as possible in the shortest time. A dry method, vacuum cleaning, was used for the rapid removal of the loose contaminant to minimize further spreading.

Dry methods. Loosely held, coarse, particulate matter can be removed quantitatively by suction. Finely divided particles, or material ground into a surface, may be only partially removed by suction.

A tank-type vacuum cleaner, equipped with a high-efficiency back-up filter (*3*), was used to remove the loosely held radium from the floors. It was estimated that about 35 per cent of the spilled radium was recovered by vacuum cleaning.

Wet methods. The results obtained by several wet methods of decontamination are summarized in Table 2.

Miscellaneous. Concrete (painted and unpainted) and wood (unpainted) were decontaminated by heating the surface with an oxyacetylene descaling torch, followed by scraping and vacuum cleaning. This removed paint and a thin surface layer of the concrete or wood flooring. The surfaces were completely restored by repainting and the decontamination was complete.

Waste Disposal

The radioactive waste, principally carpets, linoleum, and cleaning rags, filled more than two hundred drums. The drums were weighted with concrete and sunk at sea in water deeper than 100 fathoms.

Current Status

Physical examinations and breath radon analyses were made on personnel exposed to the spilled radium. No evidence was found which indicated harmful exposure for any individual. Notations were made on the medical records of the personnel involved, and periodic physical examinations will be made to detect any latent effects.

Operational clearance for the building was granted, by the agency responsible for the safety of personnel, approximately three months after the date of the spill. The operational clearance recognized that the hazard to health from radium was under control. All personal effects, homes, and automobiles were completely decontaminated within the first few days after the spill.

* * *

This article is based on a paper presented before the Radiation Division, American Industrial Hygiene Association, Los Angeles, Calif., April 21, 1953.

TABLE 2—Effectiveness of Wet Decontamination Methods

Contaminated material	*Cleaning method*	*Action of method*	*Equipment and material used*	*Condition of surface after cleaning*	*Extent of decontamination*
Linoleum*	Hot trisodium phosphate solution	Wax removal	10% TSP solution. Use rags for application and removal. Also use scouring powder, wire brushes, and swabs	Undamaged	Complete†
Wood (painted)	Hot trisodium phosphate solution	Controlled paint removal	10% TSP solution, rags, scouring powder	Undamaged	Complete in most cases
	Paint remover	Paint removal	Paint remover Paint scraper	Repainting required	Complete
Furniture, shelves, etc.	Vacuum clean Damp wipe	Dust removal	Vacuum cleaner, damp rags	Undamaged	Complete
Rubber matting,‡ rugs	Removal and disposal	—	—	—	Complete

* The linoleum in Room 110, where the spill occurred, was cracked and badly worn. As radium was ground deeply into the cracks, the floor covering was disposed of as radioactive waste.

† Complete implies decontamination to less than AEC maximum permissible level.

‡ The condition and value of the materials did not warrant intensive decontaminating efforts.

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CROSS SECTIONS

Electrodeposition of Uranium Oxide on Aluminum

By CARL R. WILSON and A. LANGER
Atomic Power Division, Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

The preparation of thin films of uranium oxide is a requisite for certain radiochemical techniques such as fission counting, and for the manufacture of some types of neutron detectors. Coatings for such purposes should be uniform and quite adherent.

A method of electroplating uranium oxide has been described by Cohen and Hull (*1*), but first attempts to reproduce this met with difficulty when plating onto bare aluminum metal was attempted. After a certain thickness the coatings would flake off spotwise and show evidence of nonuniformity of deposition. The use of different bath compositions, current densities, and methods of cleaning the base metal did not improve this situation.

A promising approach to a solution to the problem is that of subcoating the aluminum with another metal such as zinc. This was tried, and with such prepared surfaces uniform, adherent, and durable films of hydrated uranium oxide up to a thickness of 3 mg/cm² can be electrodeposited on aluminum disks and cylinders.

The aluminum surfaces are first degreased with some appropriate organic solvent such as trichloroethylene, cleaned in a hot bath of 25% sulfuric acid, and rinsed with distilled water. They are then immediately dipped into a cold zincate solution [525 gm of sodium hydroxide and 100 gm of zinc oxide in a liter of water (*2*)] for about 1 minute and rinsed with distilled water. A thin layer of zinc is formed on the surface by the chemical displacement of zinc by the aluminum.

The zinc-coated aluminum is placed in the electrolyte consisting of uranyl nitrate, in the amount required to obtain the desired film thickness, dissolved in 0.2 *N* ammonium oxalate. The *p*H of the electrolyte is initially adjusted to 8–8.5 with ammonium hydroxide, and the current density set at 0.04 amp/cm². The deposition is essentially quantitative when a temperature of about 80° C is maintained.

If hollow cylinders are to be coated both inside and outside, best results are obtained by plating the two surfaces separately, the inside generally being done first. The inside of the aluminum cylinder may be plated by using the cylinder, with the bottom plugged, as a container for the electrolyte and a rotating platinum-iridium rod as the anode. For plating the outside surface, the cylinder is rotated in the heated electrolyte, with several platinum wires serving as the anode. Rubber stoppers prevent the electrolyte from entering inside the cylinder.

The uranium oxide films produced under these conditions have a smooth velvety appearance and are sufficiently adherent to withstand considerable shock. Fission counters have been successfully constructed using this method of depositing uranium.

* * *

This work was performed under AEC contract AT-11-1-GEN-14.

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Radiation-Resistant Fused Silica

By A. JOHN GALE* and F. A. BICKFORD†

Tests carried out at High Voltage Engineering Corp. on insulating materials for accelerator tubes include high-energy electron bombardment of materials, mainly glasses, proposed or intended for this use. Specimens are bombarded in air with 2-Mev electrons incident at the rate of 10^{-7} coulomb/sec ($^1/_{10}$ μa) per cm². In general, discoloration takes place, accompanied in many cases by internal breakdown caused by trapped space charge.

Outstanding among those materials that do not break down after prolonged bombardment is a highly purified clear fused silica manufactured by Corning Glass Works—Corning fused silica. Samples also show no visible discoloration even when the specimen is viewed from the edge after 2½ hr bombardment at the above rate. Since the penetration for 2 Mev is 1 gm/cm²—about 4 mm in fused silica—this represents a total average dose equivalent to approximately 2×10^8 rep.

Specimens of clear fused silica from two other sources have also been tested. In one case a dark and mottled purple discoloration was produced after 1 min bombardment (2×10^5 rep), and in the other case a light purple was produced after 1 hr. Other materials that show small but definite discoloration are cerium-containing plate glasses and synthetic sapphire (fused aluminum oxide). Two samples, both slightly colored initially of rutile (titanium oxide) showed no marked further discoloration.

Quite apart from fused silica's other valuable properties, the Corning material should be useful where optical clarity is required in heavy radiation fields.

* High Voltage Engineering Corporation, Cambridge, Mass.
† Corning Glass Works, Corning, N. Y.

Contamination and Decontamination of Laboratory Bench-Top Materials

By W. LANE, R. FULLER, L. GRAHAM, and J. MACKIN
Applied Research Branch
U. S. Naval Radiological Defense Laboratory
San Francisco, California

Paper-laminated phenolic resins and glass-laminated polyester resins are commonly used as materials for laboratory bench tops. Representative samples of both materials have been tested for contamination, decontamination, and corrosion resistant properties according to the methods developed by Tompkins and Bizzell.* Since P^{32}, Y^{91}, and Sr^{89} were readily available at the laboratory, they were used in the contamination and decontamination studies. All sampling was done in triplicate; each recorded value is the average of three determinations.

Contamination

Samples of the material were contaminated by treating their surfaces with 0.1 ml of isotope solution (delivered by micropipette) and allowing the samples to stand for 1 hr. The excess liquid was removed with a transfer pipette, and the samples were immediately washed by immersion for 5 sec in four successive beakers of water and then soaked for 10 min in a fifth beaker of water. The samples were removed, dried under a heat lamp and their activity counted. Results are given in Table 1.

Decontamination

Detergent X (alkyl aryl sulfonate plus builders), EDTA 4 Na (ethylenediamine tetraacetic acid, tetrasodium salt) in 1% solution by weight, and 6*M* nitric acid were used in the decontamination tests. The Y^{91} and Sr^{89} were diluted to approximately the same level of activity as the P^{32} solution. Samples were contaminated with 0.1 ml of isotope solution, dried under a heat lamp, and counted. The decontaminating procedure was stepwise as follows:

Step 1. The contaminated area was treated with 0.25 ml of the reagent and allowed to stand for 3 min after which time the reagent was removed with a transfer pipette. Samples were then rinsed with a spray of water, dried and counted.

Step 2. The same samples were then treated with 2 ml of reagent, scrubbed with a bristle brush for 1 min, dried and recounted.

Step 3. Step 2 was repeated.

The extent of decontamination is denoted by the decontamination index, defined as D.I. = $\log I_o/I_f$ where I_o is the initial activity and I_f final activity.

Indices for each step of the decontaminating procedure are listed in Table 2 for the three reagents.

Samples of both materials were immersed in 3*M* solutions of hydrochloric acid, nitric acid, sulfuric acid, sodium hydroxide, and in amyl acetate, which was selected as a typical organic solvent. Visual inspections were made daily for one week. After three days, the phenolic resin samples showed signs of attack by sodium hydroxide; at the end of the week the surface was almost completely removed. Except for this attack, there were no visible effects on the surfaces of either material with any of the other reagents.

Under the conditions of this experiment, it is evident that:

1. The polyester resin adsorbs from 4 to 25 times as much activity as the phenolic.

2. Phenolic resin decontaminates more easily than polyester; in most cases by a factor of 10 or more.

3. Phenolic resin will not resist strong alkali for long periods of time. However, from a practical standpoint, this is probably not a serious matter. Otherwise, both surfaces appear to have excellent corrosion properties.

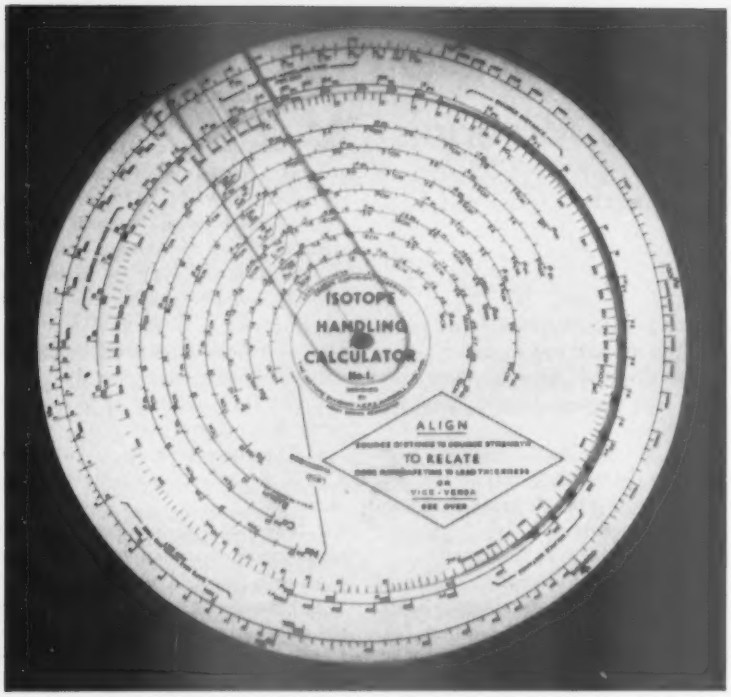
TABLE 1—Relative Contamination

	P^{32}		Y^{91}		Sr^{89}	
	Polyester	*Phenolic*	*Polyester*	*Phenolic*	*Polyester*	*Phenolic*
cpm applied	355×10^3	336×10^3	368×10^5	334×10^5	176×10^5	166×10^5
cpm adsorbed	3.1×10^3	0.12×10^3	2.1×10^5	0.34×10^5	0.56×10^5	0.12×10^5
% adsorbed	1.0	0.04	0.56	0.10	0.32	0.07
polyester / phenolic	25.0		5.6		4.6	

TABLE 2—Decontamination Indices

	P^{32}		Y^{91}		Sr^{89}	
	Polyester	*Phenolic*	*Polyester*	*Phenolic*	*Polyester*	*Phenolic*
HNO_3						
Step 1	2.4	3.8	1.7	3.1	2.1	3.0
Step 2	2.7	4.2	2.2	4.2	2.4	4.0
Step 3	2.7	5.0	2.3	5.0	2.5	5.0
Detergent X						
Step 1	2.1	2.7	1.4	2.5	1.3	1.9
Step 2	2.6	3.4	1.7	3.0	1.8	3.5
Step 2	2.8	3.6	1.8	3.2	2.0	3.8
EDTA 4 Na						
Step 1	1.8	3.2	1.3	2.0	1.4	2.1
Step 2	1.9	4.5	1.5	2.6	1.7	2.6
Step 3	2.0	5.0	1.7	3.0	2.0	3.4

* P. C. Tompkins, O. M. Bizzell, NUCLEONICS **7**, No. 2, 42 (1950); see also *Ind. Eng. Chem.* **42**, 1469 (1950).



CALCULATOR for isotope handling

Isotope Handling Calculator*

By R. WEST
Isotope Division, Atomic Energy Research Establishment
Harwell, England

The safe employment of isotopes emitting gamma radiation is dependent on a knowledge of the nature of the hazard, and a ready means of its assessment or evaluation. A small number of individually useful graphs, charts, nomograms and empirical formulas have been published on handling and shielding, but these usually require reference to decay schemes and constants. Often these do not strictly apply to the screening of sources as practiced, and frequently indirect answers are given.

This calculator has been designed on the general consideration that the wide and increasing use of gamma-ray sources, particularly in less familiar hands in industry, demands a self-contained instrument that uses direct terms, and gives simply the value of any one required. In attempting to achieve this, the scope of the calculator is restricted to use with the seven most widely used gamma-ray isotopes.

In the simplest terms, handling and shielding factors may be related as

$$D = \frac{CRK}{d^2}$$

where D is the dose-rate in roentgens per hour, C the source strength in curies, R the dose rate given by the unshielded isotope (r/hr/curie at distance d), K the fractional transmission through an absorber, and d the distance. With altered factors

$$t = \frac{d^2}{80\,(CRK)}$$

where t is the exposure time in hours that will give the maximum permissible dose of 100 mr for a normal 8-hr working day (or 500 mr/48-hr week).†

The calculator relates the above factors and their relationships in the following ways:

The values for the factor R unshielded, are taken, in r/hr/curie at 1 meter, as: Na^{24} 1.9, Co^{60} 1.3, radium (0.5 mm filtration 10% Ir/Pt) 0.84, Ta^{182} 0.605, Ir^{192} 0.27, Au^{198} 0.25, and I^{131} 0.23. These are incorporated in the calculator by scale relationships.

The values taken for the factor K are the results of attenuation measurements made with sources shielded by enclosure in lead pots, this condition applying most closely to normal shielding practice. A comparison was also made, for each isotope, of the attenuation curves using broad beams (lead pots), narrow beams (collimated), and bad conditions of scatter (flat screens). It was shown that the broad-beam values used for the factor K are sufficiently close for most other conditions of screening, e.g., incomplete surrounds, provided the scattering radiation is not significant. In addition, it was confirmed experimentally that the "inverse square" law applies, up to substantial distances, to the radiation from sources in lead pots, provided that scatter is low. The values of K obtained from the measurements are expressed as a separate scale for each isotope, in terms of lead thickness.

The required values for handling and shielding are provided directly from the calculator by means of the following scales on the calculator shown:

1. The gamma-ray dose-rate and maximum safe handling time per 8-hour day (outermost scale of the large disk).
2. Distance from the source (innermost scale of the large disk).
3. Source strength (outermost scale of the small disk).
4. Lead thickness (innermost set of seven scales, on the small disk, one scale for each isotope).

The cursor is labelled for each isotope, to insure the location of the correct scale.

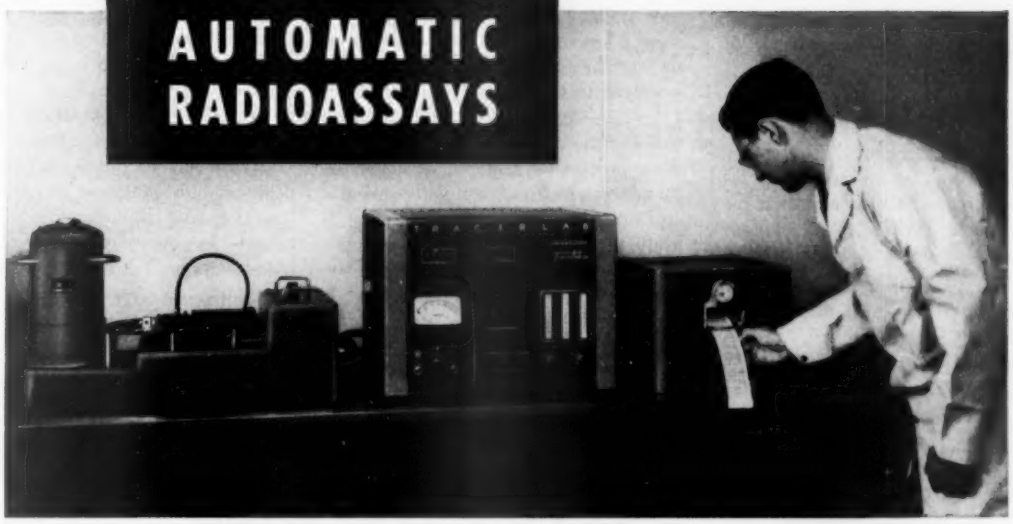
The outer scale of the large disk is marked off in roentgens per hour (D) in six logarithmic cycles, and immediately against this is marked the safe maximum working time per 8-hr day (t, in inverse proportion to D). On the next scale is the distance factor (d) in feet and meters, which is in inverse-square proportion to the dose-rate scale (D).

The outermost scale of the smaller disk is marked in curies (C) in six logarithmic cycles. Below this are the

* Based on A.E.R.E. report I/R-1063. Crown copyright is reserved.

† This dose rate should be reduced for continued and long term exposure to sources. This safe maximum value, recommended by the medical authorities (6th International Congress of Radiology 1950), may be amended in the course of time.

Reliable AUTOMATIC RADIOASSAYS



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scales for lead thickness, each isotope having a separate scale marked in centimeters and inches. The lead thickness scales are placed in relation to the scales of source strength (C), dose rate (D), and distance (d) by the factors of R given previously.

The calculator is used by aligning either scales **2** and **3** to relate **1** and **4**, or **1** and **4** to relate **2** and **3**.

In addition the instrument may be used to give the per cent or comparative transmission of radiation for the isotopes. By aligning the outer logarithmic scale directly with the lead thickness scales, the attenuation may be read off for various lead thicknesses, e.g., align Na^{24} lead thickness "0" with 100 r/hr which may conveniently be called 100%, and thus 1 in. lead gives 35% transmission, 2 in. 12%, etc.

Examples. A number of examples of general use are given:

Find the dose rate at 20 cm from a 200 mc source of Na^{24} in a lead container 12 cm thick.

Align 20 cm with 200 mc, and with the cursor against Na^{24} lead thickness 12 cm the dose rate can be read from the outermost scale i.e., 62 mr/hr or a safe handling time of just over 1½ hr/day. The illustration shows the calculator set to this problem.

An unshielded Co^{60} source of 650 mc is being used in a factory for radiographing a number of metal castings for an exposure period of 2 hr. What is the minimum radius from the source at which a safety barrier should be placed?

Set Co^{60} lead thickness "0" to time 2 hr with the cursor. The distance may then be read against the source strength of 650 mc, i.e., about 14 ft.

The same source is now to be stored in a ¼-in. thick lead safe. To what minimum radius may the barrier be moved?

Set Co^{60} lead thickness 4 in. to safe time 8 hr with cursor. Distance is read against 650 mc, i.e., 19 in.

How much Ir^{192} may be shipped in a 1-in. lead pot inside a box 12 × 12 × 12 in. to give maximum permissible surface does of 12.5 mr/hr for rail shipment?

Set Ir^{192} lead thickness 1 in. against 12.5 mr/hr with cursor. The source strength is read against distance 6 in., i.e., 85 mc.

* * *

The writer wishes to acknowledge the assistance of Mr. J. E. Evans and Mr. W. S. Eastwood with the series of absorption measurements, and with helpful discussions. Acknowledgement is also due to the Director, A.E.R.E., Harwell, for permission to publish.

Shock, Toxemia in Radiation Lethality

By ROBERTS RUGH,* JOSEPHINE SUESS,† and JOHN SCUDDER‡
College of Physicians and Surgeons, Columbia University
New York, New York

Polyvinyl pyrrolidone (PVP-Macrose),§ known in Germany as Periston or Kollidon, was injected into mice to prevent death from traumatic shock (*1*). The injections were intraperitoneal, intravenous, and subcutaneous; were protective if given as much as 72 hours prior to shock; and exerted a sustaining effect when given immediately after the shock. The polymer also gave some protection against the toxins of Clostridia, diphtheria (*2*), tetanus (*3–5*), and botulinus (*5*). Schubert (*6*) found PVP combined with tetanus toxins, exotoxins of Sonne and of Flexner's dysentery, several snake poisons and the tobacco mosaic virus. Other studies in detoxification have been reported by Dieckhoff and Ludwig (*7*), Schubert and Werner (*8*), and Dieckhoff (*9*).

There is no question but that some of the symptoms of impending X-irradiation death are similar to those of shock and toxemia. There are acute changes in the entire hematopoietic system, expressed most drastically in lymphopenia and a severe drop in blood volume. Burkle de la Camp (*10*) used PVP as a blood substitute to increase plasma volume as well as to prevent edema in both cerebral and lung surgery. Dieckhoff and Ludwig (*7*) found that PVP aided in postponing protoplasmic collapse in diphtheria infection and in histamine shock in rabbits by increasing the circulating blood volume. Anti-histamines have been used in radiation-protection studies (*11*, *12*).

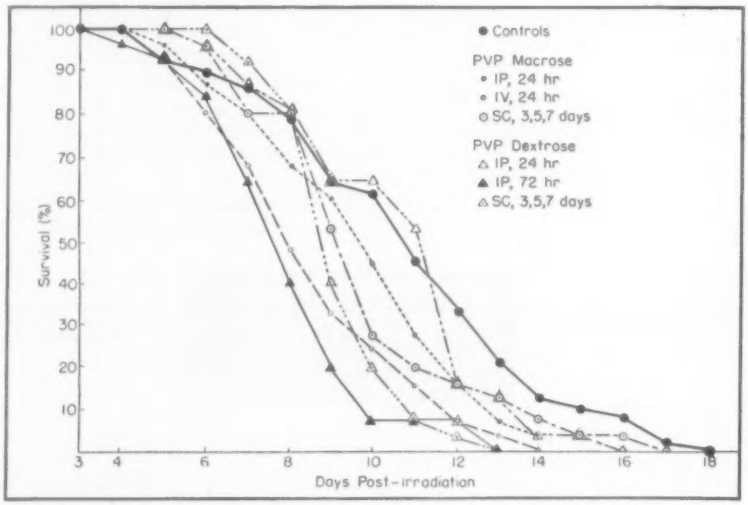
Schubert (*5*) also found that PVP aided in the excretion of substances bound by the artificial colloids without damaging in any way the cells of the liver or kidney. PVP was used in detoxification studies of mice infected with *B. coli* (*4*).

Recently Dr. John Scudder of Columbia-Presbyterian Medical Center used PVP successfully in treating various types of shock (*13*), so that it seemed in order for us to study this blood substitute as a possible antidote for the post-irradiation syndrome and lethality in mice.

* Radiological Research Laboratory.
† American Cancer Society, under direction of Department of Surgery.
‡ Director of the Blood Bank and member of Department of Surgery.
§ PVP Macrose and Dextrose supplied by Schenley Laboratories, Inc., New York, N. Y.

Materials and Methods

The CF_1 albino adult male mice of two months of age were used in these experiments since their lethality value



SURVIVAL of CF_1 male mice after exposure to 700 r X-rays. Curves are shown for controls and for mice treated with PVP Macrose and Dextrose injected in three series: intraveneous, intraperitoneal, and subcutaneous

had been established. The LD-50 at 30 days was known to be about 625 r, with 700 r as the minimum LD-100 at 30 days. This level of whole-body irradiation was used throughout so that any protection afforded by the PVP treatment would be expressed as survival.

It was first necessary to establish the tolerance dose and any toxic effects that PVP, given by the various routes, might have on the control (unirradiated) mice.

The PVP was given in three ways. The intravenous series were injected by way of the tail vein. This was found to be exceedingly tedious but was accomplished to the extent of injection of 2 cm^3 per mouse without any ill effects. The intraperitoneal injections were made through the lower right quadrant of the abdomen, and the subcutaneous injections beneath the skin of the abdomen. Every injection amounted to 2 cm^3 per treatment.

The PVP-Macrose is a 3.5% polymer in Ringer's solution, is slightly hypertonic, nonallergenic or antigenic, and is wholly stable over a wide temperature range. This substance, chemically inert in the body, has an average molecular weight of 40,000.

PVP-Dextrose is a 3.5% polymer in a solution of 5% dextrose and water, made up for experimental purposes only. Unlike Macrose there is nothing known as to its effectiveness in the treatment of shock.

The X-irradiated mice were injected with the PVP solutions following exposure to whole-body X-radiation. Irradiation at a rate of 274 r/min was by means of the Westinghouse Quadrocondex constant-potential therapy X-ray machine at 210 kv, 15 ma, 30-cm distance, with 0.5-mm Al and 0.28-mm Cu filtration. The dose used throughout was 700 r whole-body exposure at one time. Following irradiation, all mice, controls and experimentals, were given standard care in our animal quarters.

Observations and Data

A small group of male mice of the Swiss albino strain were segregated into groups and injected with PVP-Macrose at various times before exposure to 700 r whole-body X-irradiation. The results of these preliminary experiments were negative, although a few which had received intraperitoneal injection 10 minutes before irradiation showed better survival

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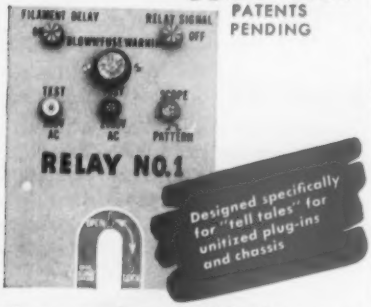

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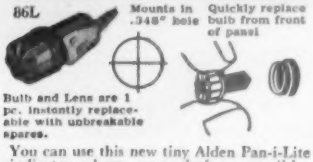
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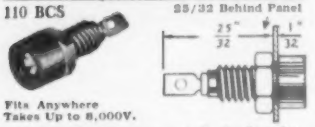

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than did the uninjected controls. Since PVP was suspected of having anti-toxic effects and since radiogenic toxins develop after X-irradiation, attention was concentrated on post-irradiation injections.

The data of a series of experiments involving some 278 male mice of the CF_1 strain are presented in the accompanying graph.

The over-all results indicate that PVP, whether in combination with Macrose or with Dextrose, does not have any protective value for mice if administered either before or after the whole-body exposure to 700 r X-rays.

Discussion

In most discussions on radiation lethality, the factors of shock similar to that caused by adrenal insufficiency, severe blood loss, and extreme stress have all been emphasized. There is no doubt but that shock is a corollary of acute radiation death. In light of the present findings, however, shock may not be the primary cause of death, but a secondary result of other and more important lethal factors. However, no claim has been made for PVP as a complete and universally satisfactory anti-shock substance, and while it may be efficacious in certain toxemias and in shock brought about by trauma, hemorrhage and burns, it is apparently nonspecific for the toxemia and shock of acute X-irradiation exposure. Not only is it nonprotective, but its addition to the irradiated mouse seems to add to its stress to such an extent that post-irradiation death is accelerated. This is in spite of the fact that injected controls have shown no ill effects.

* * *

This article is based on work performed under contract AT-30-GEN-70 for the Atomic Energy Commission in the Radiological Research Laboratory.

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INVERTED end-window counter used for liquid samples

Liquid-Sample Geiger Counter

By LEON SINGER and W. D. ARMSTRONG
Department of Physiological Chemistry
University of Minnesota
Minneapolis, Minnesota

A simple arrangement for positioning liquid samples in tubes in relation to a standard type G-M counter has been described recently.* An even more simple and more sensitive apparatus for counting gamma-ray and strong beta-ray emitters in liquids can quickly be arranged as shown in the photograph. The sample, contained in a common paraffined drinking cup, is set over the window of an inverted end-window counter. These cups, (Solo no. 67, Paper Container Manufacturing Co., Chicago, Ill.) have a flat bottom and are of the correct size to fit common end-window tubes.

Solutions of I^{131}, 5 ml in each of 10 cups, gave a mean counting rate of 1,267.3 $\pm$ 27.6 cpm (standard deviation). These results correspond to 23.08 cps per 0.1 microcurie of I^{131} with a background of 0.73 cps, as compared with 9.88 cps and 1.3 cps, respectively, obtained with the same amount of I^{131} with the previously described apparatus. It is probable that had a tube especially sensitive to gamma rays been used an even higher counting efficiency would have been obtained.

* J. U. Hidalgo, S. B. Nadler, R. T. Nieset, NUCLEONICS **11**, No. 2, 66 (1953).

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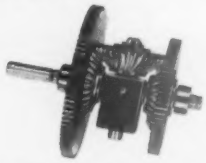

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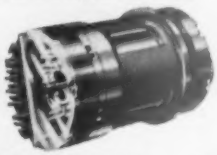

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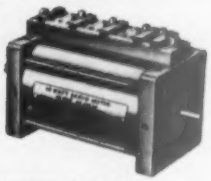

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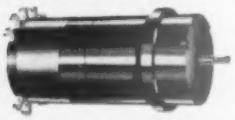

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BOOKS

Pile Neutron Research

By DONALD J. HUGHES (Addison-Wesley Publishing Co., Inc., Cambridge, Mass., 1953, xiii + 386 pages, $8.50). Reviewed by LYLE B. BORST, Department of Physics, University of Utah, Salt Lake City, Utah.

The field of neutron physics has grown like Topsy since its birth with classified wartime research projects. Postwar publication has been somewhat sporadic, being encumbered, in addition to the usual barriers, with the requirement of declassification if originally classified. As a result, the open literature is less systematic and complete than would normally be the case.

The presentation in this book is directed to the level of a first-year graduate student, and for the most part achieves its objective. Material is presented in a straightforward form with an adequate set of references to supplement the text. A real effort has been made to confine these references to the normal, open literature. This in large measure is successful, although perhaps 20% are to AEC reports of one variety or another. One also finds rather unusual scientific sources quoted such as "AEC press release," and "Semiannual Reports of AEC to Congress."

Topics covered would fill several volumes if completely presented. The choice of illustration by example is therefore appropriate. The book is neither exhaustive nor definitive, being confined primarily to work conducted by the author.

The nature of the chain reaction is briefly presented in a form easily understood by experimenters. It is therefore possible for the uninitiated to develop sufficient appreciation of the virtues and limitations of reactors to permit him to design effective experiments before having contact with an operating unit. A valuable auxiliary for this purpose is the presentation of the final chapter on health physics, designed to give the experimenter an understanding of the precautions required for reactor research.

The organization is experimental in form, giving research techniques of general utility, then discussing techniques used in studies with neutrons in the various energy regions: fast (10^5–10^7 ev), resonance (0.1–10^5 ev), thermal (0.01–0.1 ev), and cold (<0.01 ev).

The scientific contribution of the book is significant, since it pulls together a wealth of unorganized research data appearing in the normal periodical literature, as well as Atomic Energy Commission reports, and gives them a logical sequence. The fitting together and interpretation of the recent work on the optical properties of cold neutrons is perhaps especially significant.

The appendixes include the most recent set of thermal-neutron cross sections tabulated as total, activation, and various scattering cross sections. A set of experiments used for instruction at Argonne National Laboratory has been included to show the varieties of studies open to first-year graduate students.

Pile Neutron Research, although not intended as a classroom text, has been so used successfully. It was found more satisfactory than other presentations in the field. It is a significant contribution to a growing field of research and will certainly be a cornerstone in this branch of nuclear physics.

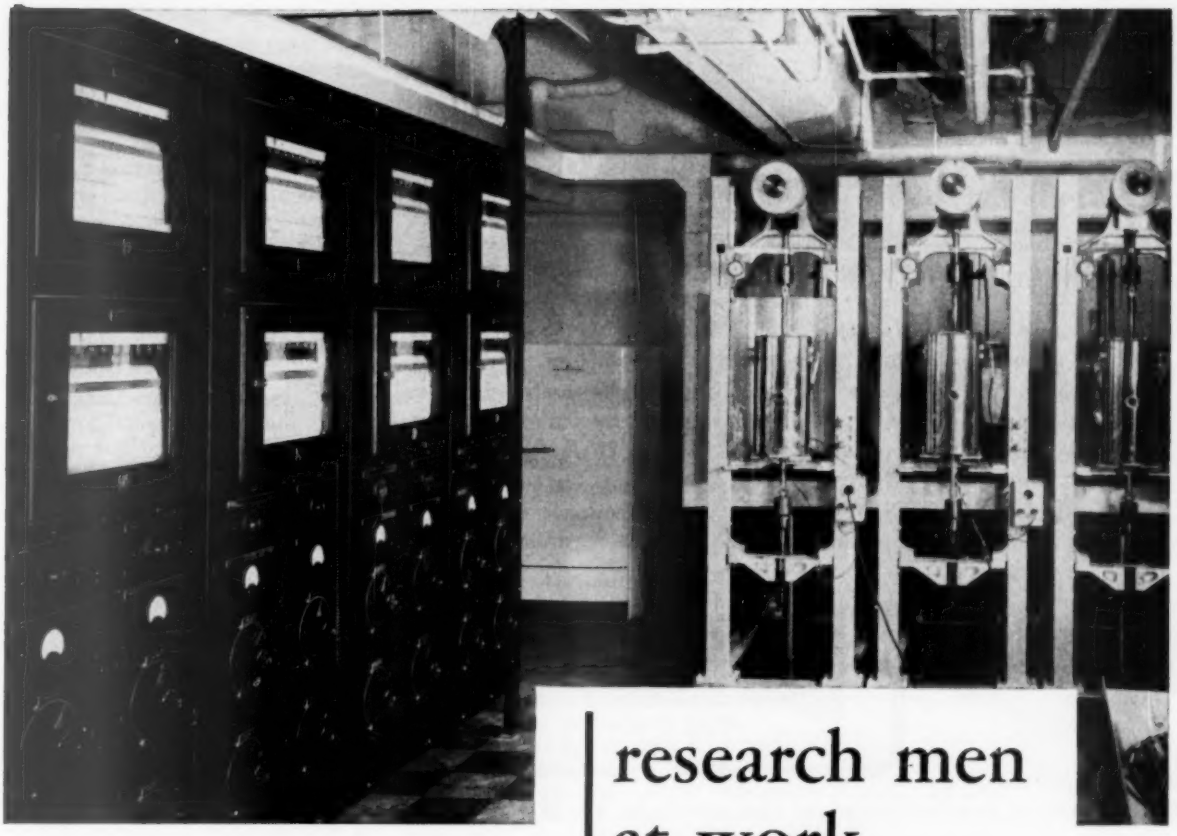
Signal, Noise and Resolution in Nuclear Counter Amplifiers

By A. B. GILLESPIE (McGraw-Hill Book Co., Inc., New York, 1953, xii + 155 pages, $4.50). (Also Pergamon Press Ltd., London.) Reviewed by J. B. H. KUPER, Instrumentation and Health Physics Department, Brookhaven National Laboratory, Upton, N. Y.

This book is the first of a series of monographs on applied modern physics and communications sponsored by Pergamon Press, Ltd., and under the editorship of D. W. Fry of Harwell. As such, it is particularly interesting since it is the announced objective to keep the time required for publication of the monographs to a minimum so that it is possible to present original work as well as collations of information.

The rather specialized subject of the optimum design of pulse amplifiers for nuclear counters has received very little attention in the literature, and the present book fills a long-felt want. The discussion is confined almost entirely to the input stage of a counter amplifier to be used with a pulse ionization chamber, with only such references to the properties of the succeeding stages and the ion chamber itself as are strictly necessary to an understanding of the subject.

After a brief introduction, chapter 2 contains information on the nature of



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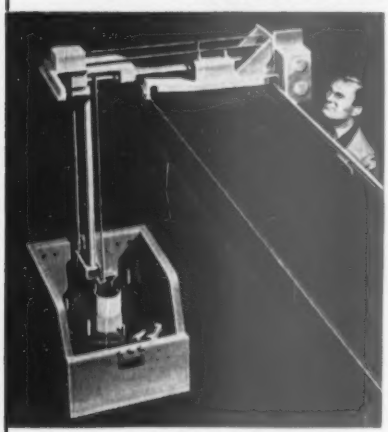

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the signals to be handled, and chapter 3 discusses the various forms of tube and circuit noise. Next comes the discussion of signal-to-noise ratio, including the effects of the various methods of pulse shaping.

Chapter 5 is devoted to a consideration of amplifier sensitivity in energy and total activity measurements, and the sixth, and final, chapter discusses the applicability to proportional and scintillation counters of the results previously obtained.

Although chapters 1, 2, and 6 contain much material previously published, the remaining chapters are largely composed of unpublished theoretical and experimental data. Chapter 5, in particular, contains an analysis of the useful sensitivity of amplifiers in total activity measurements that is largely original.

Thanks to the fact that all derivations and integrations have been relegated to a series of appendices the book is unusually readable. It should prove valuable both to the novice in the field of nuclear science and to the experienced nuclear physicist or chemist who wishes to secure optimum performance with respect to sensitivity or speed in a particular experiment. It is a pleasure to recommend it highly, and this reviewer is looking forward eagerly to the appearance of other volumes in the series.

BOOKS RECEIVED

Zirconium and Zirconium Alloys, American Society for Metals, 7301 Euclid Ave., Cleveland, Ohio, 1953, 354 pages, $7. This is the transcript of the 21 papers presented at the symposium on Zr and Zr alloys held during the Eighth Western Metal Congress and Exposition, Los Angeles, March 23–27, 1953.

Electron Optics, by O. Klemperer, Cambridge University Press, New York, 1953, xii + 471 pages, $9.50. This second edition of a book originally published in 1939, gives an account of the principles, methods, and applications of geometrical electron optics To deal with the present state of development of the subject, the book is six times the size of the original edition.

The Scientific Adventure, by Herbert Dingle, Philosophical Library, New York, 1953, ix + 372 pages, $6.

This book, by a professor of history and philosophy of science at University College, London, is a collection of lectures and essays. There are two major divisions to the book. The first,

Historical Essays, deals with general areas in the history of science, and with such men as Copernicus and Galileo, in particular. The second part, *Philosophical Essays*, is concerned with such subjects as nature of scientific philosophy, laws of nature, and science and ethics, among others.

Chemical Constitution, by J. A. A. Ketelaar, Elsevier Press, Inc., Houston, Texas, 1953, viii + 398 pages, $6.50. The subtitle of this book is "An Introduction to the Theory of the Chemical Bond."

Luminescence and the Scintillation Counter, by S. C. Curran, Academic Press, Inc., New York (or Butterworths Scientific Publications, London), 1953, x + 219 pages, $5.80. (*To be reviewed.*)

Mathematical Physics, by Donald H. Menzel, Prentice-Hall, Inc., New York, 1953, vii + 412 pages, $11.35. This book has been designed for use in junior, senior, or graduate courses on the subject.

Atoms, Men and God, by Paul E. Sabine, Philosophical Library, New York, 1953, x + 226 pages, $3.75. This is a research physicist's ideas on the relation of the concepts of modern science and psychology to the intellectual content of Protestant religious faith.

The Stability of Rotating Liquid Masses, by R. A. Lyttleton, Cambridge University Press, New York, 1953, 150 pages, $6.50.

ALSO OF NOTE

Microwave Spectroscopy, by Walter Gordy, William V. Smith, and Ralph F. Trambarulo, John Wiley & Sons, Inc., New York, 1953, xii + 446 pages, $8. This book was written with the purposes of facilitating analysis and interpretation of microwave data, helping the beginner to become familiar with the instruments and methods, and providing a source of the large amount of information that has been obtained through microwave spectroscopy.

Water Pollution Research (Department of Scientific and Industrial Research, Ministry of Supply). This report of the Water Pollution Research Board contains a section on removal of radioiodine during the normal treatment of domestic water supplies. *British Information Services, 30 Rockefeller Plaza, New York, $0.65.*

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NEWS

Joint Committee Begins Open Hearings on Development of Nuclear Power; To Hear from All Interested Groups

The Joint Committee on Atomic Energy began, on June 24, an extensive series of open hearings on problems in the development of nuclear power. The information and opinions gained at these hearings will be used to guide the committee in its actions on proposals for amendment of the Atomic Energy Act of 1946 (NU, July '53, p. 64; June '53, p. 88).

At this writing, nine sessions of the series of hearings have been held, and seven more sessions have been scheduled, to run to the end of July. In the September issue, NUCLEONICS will publish the important details of the matters taken up at the meetings.

The first meeting was devoted to testimony by representatives of the Atomic Energy Commission. Those appearing were Gordon Dean, chairman, Lawrence R. Hafstad, director of the reactor division, W. L. Davidson, director of the office of industrial development, John C. Bugher, director of the division of biology and medicine, and J. G. Beckerley, director of classification.

Testimony at the second meeting was heard from Walter Bedell Smith, Under Secretary of State, Robert LeBaron, assistant to the Secretary of Defense, and I. I. Rabi, chairman of the general advisory committee of AEC.

The third meeting heard testimony from Douglas McKay, Secretary of the Interior, Walter Williams, Under Secretary of Commerce, and Dale E. Doty, member of the Federal Power Commission, who was accompanied by Francis L. Adams, chief of the bureau of power, FPC, and Howard E. Wahrenbrock, assistant general counsel, bureau of law, FPC.

The fourth meeting was devoted to testimony by the five industrial teams that have been making nuclear power feasibility studies. Representatives of these groups that attended were Walker L. Cisler, president, Detroit Edison Co., Tyrone Gillespie, general counsel, Dow Chemical Co., Edwin J. Putzell, Jr., secretary, Monsanto Chemical Co., J. W. McAfee, president, Union Electric Co., Earle W. Mills, president, Foster Wheeler Corp., Fred C. Kellogg, president, Pioneer Service and Engineering Co., Willis Gale, chairman, Commonwealth Edison Co., and Murray Joslin, vice president, Commonwealth Edison Co.

Testimony at the fifth meeting was heard from Walter H. Zinn, director of the Argonne National Laboratory, Alvin M. Weinberg, director of research of the Oak Ridge National Laboratory, Chauncey Starr, director of the atomic energy research department of North American Aviation Co., Karl Cohen, vice president of Walter Kidde Nuclear Laboratories, and John R. Menke, president of Nuclear Development Associates.

At the sixth meeting, testimony was heard from Gwilym A. Price, president, and Charles H. Weaver, manager, atomic power division, Westinghouse Electric Corp.; F. H. McCune, general manager, atomic products division, General Electric Co.; Arnold K. Brown, executive vice president, American Machine and Foundry Co.; and Eugene P. Wigner, general advisory committee, AEC.

The seventh meeting heard from J. L. Atwood, president, North American Aviation Co., R. S. Stevenson, executive vice president, Allis-Chalmers Mfg. Co., and C. R. Braun, manager, atomic power section, Allis-Chalmers.

Those testifying at the eighth session were George L. Weil, formerly of AEC's reactor division, and Clyde Ellis, general manager, National Rural Electric Cooperative Association.

The ninth meeting heard testimony from E. R. Rowley, production manager, National Lead Co., and Alfred Iddles, president, Babcock & Wilcox Co.

Union Carbide Co. has sent the committee a letter stating that it wants to be identified with the testimony of Alvin Weinberg given at the fifth meeting. Dupont and Kaiser Engineers have both informed the committee that they do not want to testify. A statement from Jerry Voorhis, executive director, Cooperative League of the U. S. A., has been submitted for the record.

The Joint Committee has stated that it would be happy to receive, for possible inclusion in the record, statements from any individual or organization on matters related to the subject of the hearings.

Lewis L. Strauss Succeeds Gordon Dean as AEC Chairman; Had Been One of Original Commissioners

Lewis L. Strauss, member of the Atomic Energy Commission from 1946 to 1950, has been appointed to succeed Gordon Dean as commissioner and chairman of AEC. Strauss has been acting as President Eisenhower's special advisor on atomic energy policy since early this year (NU, April '53, p. 67). Dean left AEC on June 30 (NU, March '53, p. 70) and Strauss took over at that time.

The reappointment of Strauss to AEC is expected to aid the cause of industrial nuclear power. As Presidential advisor, he took an active role in aiding the development of electric power from reactors. He also strongly backed AEC's bid for funds for research and development on power reactors.

During his first term as a commissioner, Strauss was the only commissioner to oppose shipment of radioisotopes to certain foreign countries. His reasons for opposing the shipments have generally been misunderstood. During testimony to the Joint Congressional Committee on Atomic Energy in 1949, Strauss said that the opposition he had made in 1947, and still maintained in 1949, was based on strict interpretation of the McMahon Act.

Strauss based his objection to shipment of the radioisotopes on statements in the Act that "practical industrial applications of atomic energy" are to be shared and disseminated "as soon as effective and enforceable safeguards against its use for destructive purposes can be devised," and that "until Congress declares . . .

that effective and enforceable safeguards against the use of atomic energy for destructive purposes have been established, there shall be no exchange of information with other nations with respect to the use of atomic energy for industrial purposes."

In insisting that the letter of the law be followed, Strauss said he felt that there existed the possibility that the isotopes might be used to gain engineering knowledge that could advance a country's military strength. In this case, he indicated, it was not the province of AEC to make a liberal interpretation of the law.

Study to be Made for High-Cost Power Reactor

The Atomic Energy Commission has awarded a contract to Walter Kidde Nuclear Laboratories, Garden City, N. Y., to make a design study for a nuclear power plant for use in an isolated high-cost power area.

The study will concentrate on a plant with a 30,000-kw capacity run by a power-only reactor. The reactor would use light water as both moderator and coolant.

The type of area in mind for such a plant is one where electric power is not readily accessible at usual costs. Investigations of where such areas might exist have been made (NU, Apr. '53, p. 32; May '53, p. 14).

The contract between AEC and the Kidde organization calls for a detailed cost analysis to cover architect-engineer costs, construction costs, and operating costs for a four-year period following start-up of the plant.

The contract also specifies that the study point out the effect of site location upon reactor design and power cost. It is expected that the study will be completed late this year.

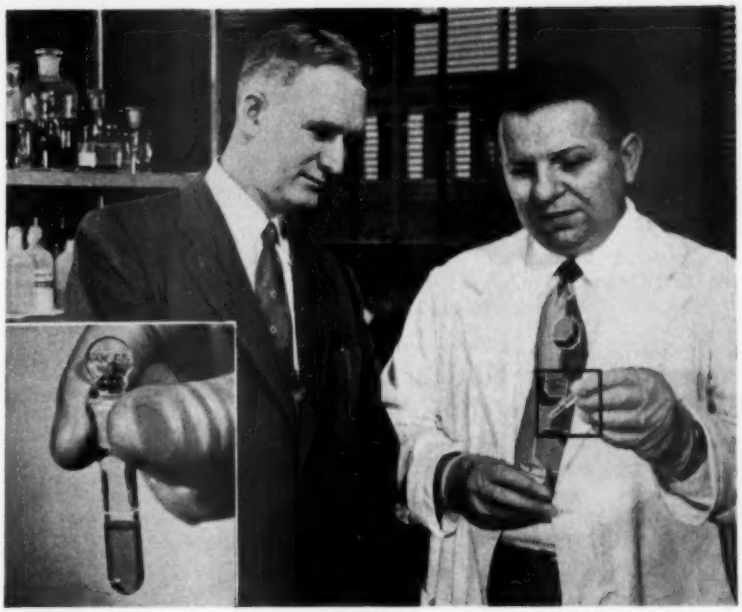
Joseph Campbell Named to Fill AEC Vacancy

Joseph Campbell, treasurer of Columbia University and its vice president in charge of business affairs, has been nominated by President Eisenhower to membership in the Atomic Energy Commission.

He is to fill out the unexpired term of T. Keith Glennan who resigned in October. The term expires on June 30, 1955.

Campbell holds an award for work with the Manhattan Engineer District and the certificate of merit of the Office of Scientific Research and Development.

With the appointment of Campbell and the recent appointment of Lewis L. Strauss, the AEC is now at full membership.



FIRST PLUTONIUM PRODUCED in Argonne National Laboratory's Experimental Breeder Reactor is being shown to laboratory director W. H. Zinn by Stephen Lawroski, director of the laboratory's chemical engineering division. Inset shows vial of yellow solution of plutonium salt. Rate of breeding in reactor is determined by comparing rate at which U-235 atoms in core are undergoing fission and rate at which U-238 atoms in surrounding blanket are converted to Pu-239

Conference on Reactors to be Held in Norway

The Norwegian-Dutch Joint Establishment for Nuclear Energy Research will be the host at a three-day conference on heavy-water reactors to be held August 11–13, 1953, at Kjeller, Norway. Visitors from 19 countries will attend the six sessions of the conference.

The first session will be on design and construction, with Alvin M. Weinberg, U. S., acting as chairman. Speakers will be John V. Dunworth, England, John M. West, U. S., and Leo Kowarski, France. The discussion of design and construction will be continued at two other sessions. Chairman for the second part will be Sigvard Eklund, Sweden; the speakers will be Stuart McLain, U. S., and Odd Dahl, Norway. Leo Kowarski will be chairman for the third part.

There will be a session on kinetics and control, with John V. Dunworth as chairman. Speakers will be Arne Lundby, Norway, Alvin M. Weinberg, and Victor Raievski, France.

Finally, there will be a two-part session on neutron physics. Paul Scherrer, Switzerland, will be chairman of the first part; Jacob A. Goedkoop, Norway, B. B. Kinsey, Canada, and Peter A. Egelstaff, England, will be the speakers. Manuel Sandoval Vallarta, Mexico, will be chairman of the second part.

Most of the sessions have time allotted for short contributions and discussion. There will also be opportunity for conference members to visit the establishment at Kjeller.

Radioisotopes in Medicine Subject of ORINS Course

An advanced course on the clinical applications of radioisotopes will be given Sept. 14–25 by the Oak Ridge Institute of Nuclear Studies. Participation will be limited to physicians who have had clinical experience with radioisotopes.

Subjects to be covered include tumor localization, circulatory volumes and outputs, fluid and electrolyte spaces,

therapy of blood diseases, theory of radiation dosimetry, radioactivity measurement, Au^{198} and other colloids, interstitial and surface applications, teletherapy, I^{131} in diagnosis and therapy, and external counting.

The course will consist of lectures, clinics, and exhibits of equipment. Speakers have been selected from among the leaders in the specific fields.

Application blanks may be obtained from Special Training Division, ORINS, Box 117, Oak Ridge, Tennessee.

Plans Proceed for Nuclear Engineering Conference

Plans are almost complete for the three-day conference on nuclear engineering to be held at the University of California, Berkeley, Sept. 9–11, 1953 (NU, May '53, p. 74).

Final selection of papers was to be made by July 15 from about 60 acceptable abstracts.

The first part of the conference is on reactors and nuclear power plants. The papers in this part are grouped in four subdivisions: technical aspects; kinetics, instrumentation, and control; engineering economic aspects; and reactor designs and descriptions.

The other three parts of the conference are on isotope production and separation, isotope handling and utilization, and accelerator engineering.

It is planned that bound copies of preprints of the talks to be given will be available to those attending the conference.

AEC Budget Allows for Multi-Bev Cyclotron Studies

The original Atomic Energy Commission budget for fiscal 1954 carried an item of $5-million for construction of a multi-Bev strong-focusing cyclotron, but, in the final budget submitted to Congress, this was reduced to $1-million, a figure calculated to allow for further studies and possibly some model tests.

According to AEC commissioner H. D. Smyth, the higher figure was put in "when some ideas for building one of those big machines had just been brought forward, and with the usual over-optimism about new ideas the thought was they were so good, perhaps, that it would be possible to build a bigger machine for $5-million.

"Further examination has shown that, although these ideas are good and will be very useful and will make it

AEC Office of Industrial Development displayed materials, processed, and equipment developed in atomic energy field and available for general industrial use

W. Davidson, OID director (right) and G. Manov, assistant director, discuss absolute air filter display with J. Ayer, of Cambridge Corp., manufacturer of the unit

Exhibits Show AEC, Industry Activity

A growing industrial interest in the atomic energy field was clearly indicated by three exhibits in the Exposition of Basic Materials for Industry, in New York recently. Two firms indicated that they were already preparing for an expanding atomic energy market for materials.

A positive approach to interesting industry in atomic energy and the products of atomic energy research was taken by the Atomic Energy Commission's Office of Industrial Development (OID). Its exhibit was so successful that future showings are being planned.

Sylvania's model of reactor power plant is explained to C. H. Prange, Austenal Labs, Inc. (right) by R. A. Jewett. Sylvania is working with AEC on development and manufacture of fuel elements, other reactor components. W. E. Kingston, Atomic Energy Division director, told NUCLEONICS that "we plan to be ready with facilities to manufacture fuel elements and components in the needed quantities" when commercial use of atomic power is achieved

N. C. Bartholomew, vice president of Carborundum Metals Co. (left) tells J. Atherton, Brookhaven National Laboratory, that "all pure Zr and Hf sponge are now processed for AEC, but metal for commercial applications will be produced by us in 1953"

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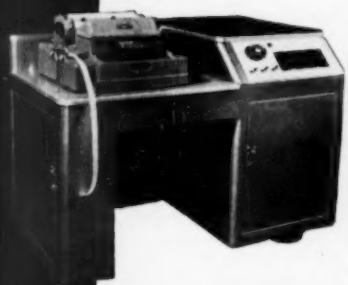

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practically possible to build a big machine such as the West European laboratory wants to build, the cost will still be greater than $5-million to go to anything that would be worthwhile."

Plan Week-Long Conference on Nuclear Engineering

A week-long meeting on nuclear engineering will be held at the University of Michigan next year under the auspices of the American Institute of Chemical Engineers and the university's department of chemical and metallurgical engineering.

In addition to men from this country, foreign engineers and scientists now working on atomic energy and similar problems will be invited to participate in the meeting.

The program, to take place June 20–26, 1954, will be in eight parts. Each of these will be full-scale conferences covering, within the bounds of security, the latest developments in the field.

Major divisions of the program and the chairmen are *Education*, Robert Ernst, University of Louisville; *Reactor Types and Technology*, Lawrence C. Widdoes, Monsanto Chemical Co.; *Materials of Construction*, Miles C. Leverett, General Electric Co.; *Nuclear Reactor Engineering*, James A. Lane, Atomic Energy Commission; *Processing of Irradiated Materials*, Stephen Lawrowski, AEC; *Reactor Fuel Refining and Preparation*, John Clegg, Battelle Memorial Institute; *Application and Uses of Radioactive Products*, Lloyd E. Brownell, University of Michigan; and *Social Impact of Nuclear Science*, F. J. Van Antwerpen, *Chemical Engineering Progress*.

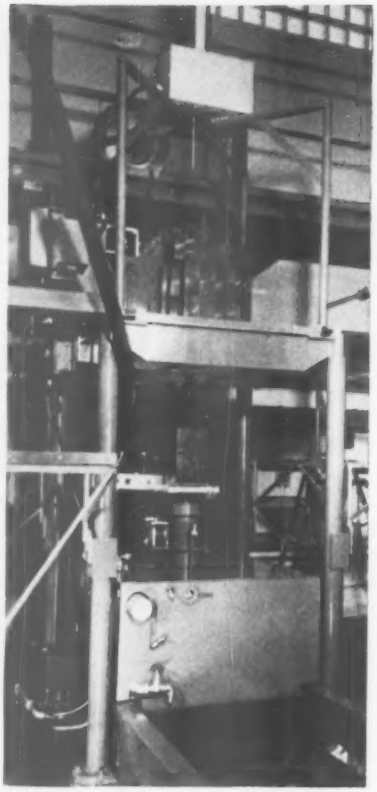
The conference is under the direction of Donald L. Katz, chairman, department of chemical and metallurgical engineering of the university, and committee on nuclear energy, American Institute of Chemical Engineers.

Nuclear Power in Canada to be a Private Enterprise

Responsibility for the production of commercial nuclear power in Canada will rest with private enterprise, according to C. D. Howe, minister of trade and commerce.

The government does not plan to go further than the completion of the big new reactor now under construction at Chalk River, and which is expected to be finished in 1954 or 1955. "When it is finished," Howe said, "the plans of Atomic Energy, Ltd., will be completed as far as Chalk River is concerned."

He also said that "methods of producing commercial power are now fairly well developed. We hope private industry will undertake building a reactor for commercial power. I am not going to ask the government to build this reactor because I do not think it a proper government operation."



"TOPSY," CRITICAL ASSEMBLY at Los Alamos Scientific Laboratory is one of the remotely controlled machines used there to study properties of fissionable materials. Rectangular block of neutron-reflecting material on top of hydraulic cylinder holds part of critical mass; other part is inside housing directly above the block. Chain reaction is started by bringing two parts together and inserting normal uranium control rods in openings in reflector. Machine uses enriched fissionable material and operates on modest power. Controls and TV viewer are located ¼ mile away

South Australia Plans Nuclear Generating Station

South Australia hopes to have a 100,000- to 400,000-kw nuclear generating station operating by 1958, according to a recent statement by S. B. Dickinson, State Director of Mines.

"South Australia has very low fuel reserves, and is possibly the one area

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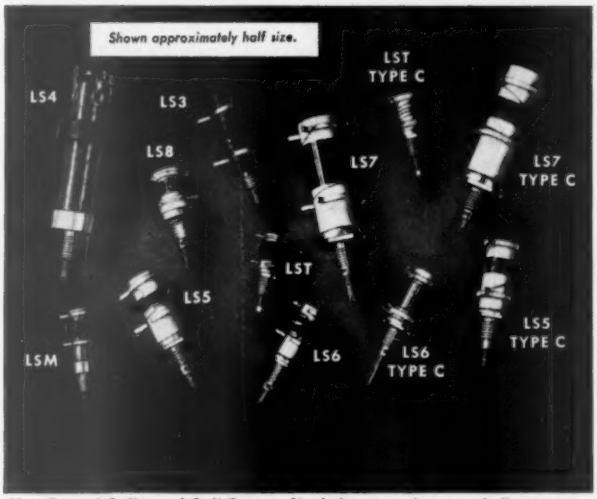

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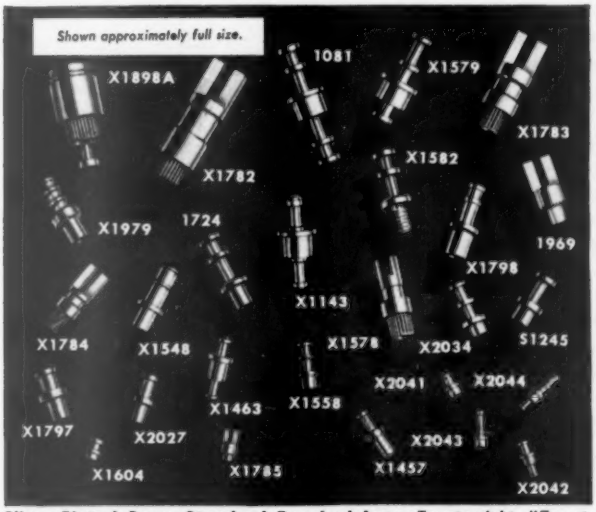

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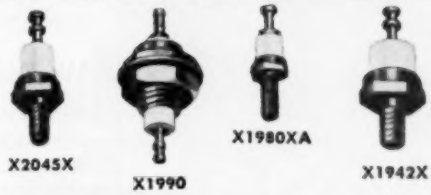

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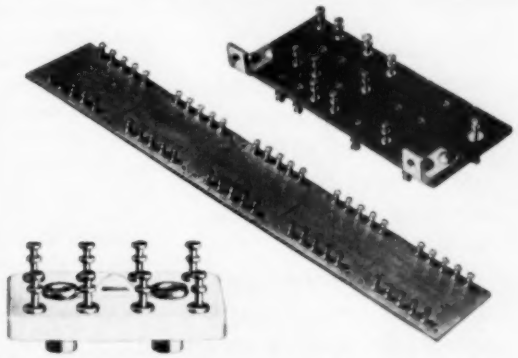

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in the British Commonwealth where atomic energy would be economical today," Dickinson said.

It is expected that extraction of the uranium fuel from ore would be carried out at Port Pirie. The government plans to continue its purchases of uranium and the encouragement of private companies and prospectors.

RAW MATERIALS

United States. Most of our uranium now comes from sources outside North America, and substantial dependence on overseas sources will continue for some time. There is reason for concern about whether all uranium needed for maximum production in U. S. plant operations for the next year or two will be available. It is possible that uranium stocks on hand will have to be drawn down to lower levels than is considered desirable. It may even be necessary to resort to operational adjustments which would minimize the effect of a uranium shortage on weapon production.

The longer range outlook for uranium procurement is more encouraging. An annual procurement goal has been established that is substantially greater than amounts bought in 1952. Developments in Canada, the Union of South Africa, Australia, and the U. S. indicate that the goal may be reached in about five years. With the growth of these new sources, the Belgian Congo will no longer occupy such a dominant position in the over-all picture, but is expected to continue making a substantial contribution to total requirements.

The Atomic Energy Commission is convinced that it is of utmost importance to procure all the uranium possible at reasonable prices. Every pound that suppliers may offer is needed, and they are being encouraged to increase production in future years.

Hanford. A plant built for recovery of uranium from sludge is now in full operation, and the process is said to be working out very well.

IN BRIEF

• **AEC scientists.** The 1954 budget provides for the employment of about 5,800 scientists in AEC laboratories.

• **Plant expansion.** At Hanford, one new reactor has gone into operation and two chemical processing plants have begun operating. At Savannah River, the supporting facilities are rapidly nearing completion and some are already in operation preparing materials for start-up of the first of the major production units there. Detailed analyses of requirements, plus some minor modifications have made it possible to eliminate from the expansion program one facility at Savannah River.

• **Storage tanks.** Fifteen huge underground tanks will be built inside the barricades of the Hanford Works. Grove, Shepherd, Wilson & Kruge, Inc., Seattle, submitted a low bid of $2.4-million. The tanks will increase the waste storage facilities at the project.

• **Food preservation.** Studies are underway at University of Chicago for possible uses of fission wastes for food preservation. A 50-r Co^{60} source is being used for the work.

• **Soviet radioisotopes.** Medical and biological experimentation with artificially-produced radioisotopes is being carried out by Soviet scientists.

• **Radiopalladium in diesels.** Research at the University of Michigan has shown that incorporation of radiopalladium in diesel engine metals makes possible lower compression ratios and greatly increased engine efficiency.

NEWSMAKERS

G. Failla of Columbia University has been elected president of the Radiation Research Society, and **H. J. Curtis** of Brookhaven National Laboratory has been elected vice president. **A. Edelman** of Brookhaven and **H. Patt** of Argonne National Laboratory have been reelected secretary and treasurer, respectively.

Bruce R. Prentice has been named manager of atomic power study of the atomic products division of General Electric Co., Schenectady.

G. W. Morgan is the new chief of the advisory field service branch of the Atomic Energy Commission's isotopes division at Oak Ridge. **Oscar M. Bizzell** has been appointed assistant chief.

W. Tom Moore has been named an executive assistant in the atomic power division of the Babcock & Wilcox Co.

Charles E. Winters, acting director of the reactor experimental engineering division at Oak Ridge National Laboratory, has been appointed to the new post of assistant research director.

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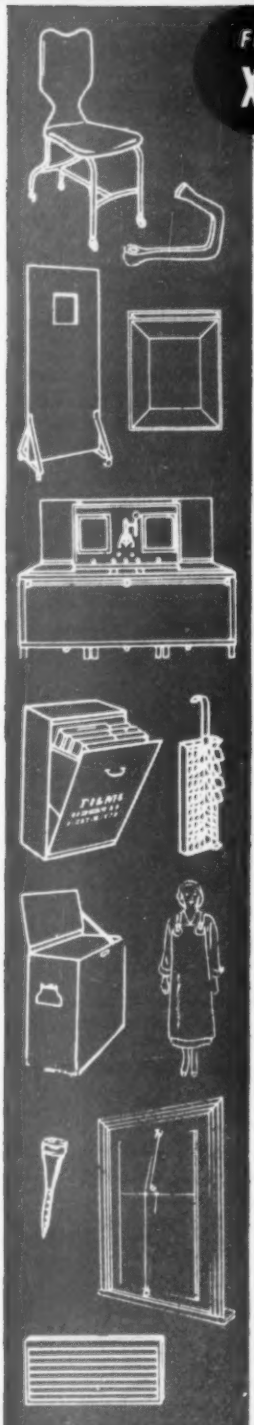

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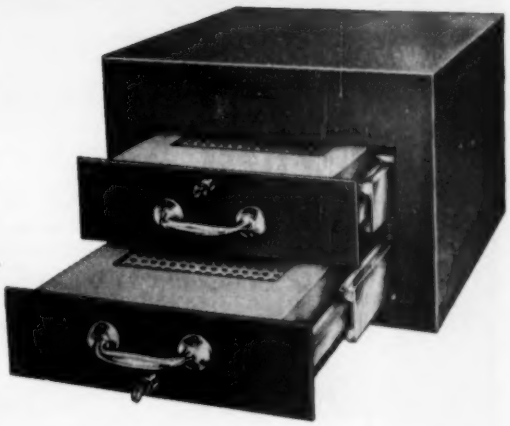

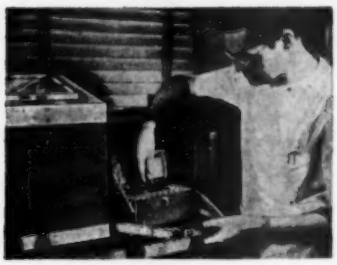

At left is shown a portable radium carrier for transporting radium from safe to place of use. Also shown is a radium screen for viewing radium handling operations.

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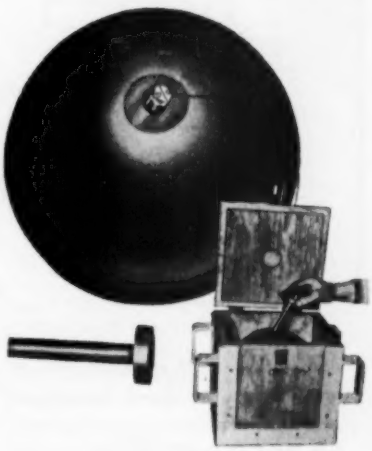

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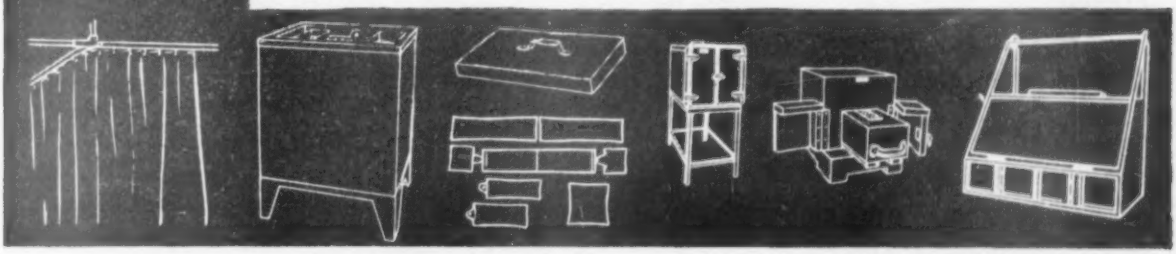

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LETTERS

Yugoslavian Research

DEAR SIR:

This letter serves to add information about activity in the nuclear sciences in Yugoslavia to the report "World Progress in Atomic Energy" (NU, Dec. '52, p. 7).

After the war, construction was begun of three natural sciences research institutes in Belgrade, Zagreb, and Ljubljana. These institutes are now completed and in operation, with the one in Belgrade oriented exclusively towards nuclear science and atomic energy.

This Institute for Nuclear Sciences "Boris Kidric," until recently the Institute for Research of the Structure of Matter, was begun in 1948. The initiative and leadership of this project was supplied by Professor Pavle Savic, known for his work with Madame Joliot Curie in Paris on the discovery of the fission of uranium in 1938. Soon after the Institute was started, Savic was joined by his friend Dr. Robert Walen, formerly of the Institute Curie in Paris, who now takes an active part in the leadership of the Institute and is head of the physics laboratory. The present director of the Institute is Stevan Dedijer, a graduate in mathematical physics from Princeton.

The first job tackled was to form young scientific and engineering cadres, since before the war there was no tradition in nuclear science in Yugoslavia. Today, in five laboratories, there are about a hundred young people working on a variety of problems.

The physics laboratory, having constructed the basic instrumentation and worked out techniques for its use, works on nuclear spectroscopy and a number of neutron physics problems. For this and other purposes the Institute has a Cockcroft-Walton 1.5-Mev accelerator, a 100-kev high-tension set, a 1-curie radium-beryllium source from Harwell, and 1 gm of radium solution.

The physical chemistry laboratory, under the direction of Prof. Savic, works on problems of making metallic uranium, of impurities in uranium, Szillard-Chalmers reactions, kinetics of chemical reactions, etc.

The technological laboratory, in cooperation with the chemistry laboratory, is studying the process of obtaining pure uranium from ores.

The biological laboratory is studying health physics and the effects of radiation on cells.

The applied mathematics laboratory works on servomechanisms and mathematical machines. It has constructed an analog machine for the solution of systems of up to 30 linear algebraic equations.

Up to now, the Institute has constructed its own scalers, amplifiers, G-M beta and gamma counters, scintillation crystals, etc. It has published two collections of scientific papers in English and French during the past year; these are sent to all centers in various countries engaged in similar work. It has an active collaboration and exchange with European laboratories and has a number of people working in various atomic energy centers.

For the last few months, the Institute has had a group, headed by the writer, engaged in making preliminary studies for a heavy-water reactor.

MILORAD RISTIC
Institute of Nuclear Sciences "Boris Kidric"
Belgrade, Yugoslavia

Wide-Range Instruments

DEAR SIR:

One of my associates directed my attention to the article "An Improved Wide-Range Radiation Instrument" by Burgwald and Reiffel (NU, Mar. '53, p. 46). We have used the principles of dynode voltage feedback for some time to obtain a logarithmic response of photomultiplier tubes to a very wide range of radiation levels. An article describing the principal features of such a circuit was published in *Electronics* **19,** No. 11, 105 (1946).

We believe that the features of this basic circuit may represent some attractive advantages over the device of Burgwald and Reiffel since:

1. The self-balancing operation is performed electronically and instantaneously.

2. A compensating circuit is incorporated, rendering the scale very nearly linear over a wide range, and the principles are extensible to the total range of the instrument.

3. The output of this circuit is sufficient to operate high-speed linear ink recorders without supplementary complications.

Another article in a recent issue of

Electronics (1953) describes modifications of the basic circuit in which the scale has been extended somewhat, and therefore its utility in certain applications has been improved.

Instruments of this type are available commercially in the form of the "Macbeth-Ansco" model 12 color densitometer (Macbeth Corp., Newburgh, N. Y.) and have been used fairly extensively in the photographic industry for measurement of color and black-and-white densities.

An article "An Improved Photomultiplier Tube Color Densitometer" (*J. Soc. Motion Picture Television Engrs.* **54,** No. 1, 35, 1950), outlines some of the theoretical reasons why the basic circuit can be expected to give improved performance over the simpler linear circuits.

MONROE H. SWEET
Physics Research Laboratory, Ansco
Binghamton, New York

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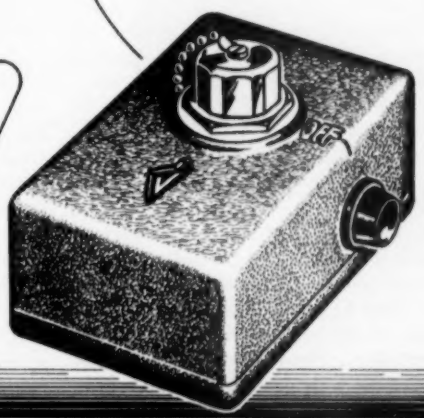

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New AEC Patent Releases

THE FOLLOWING PATENTS, released by the Atomic Energy Commission, are available for royalty-free, nonexclusive licensing. Applicants should apply to the Chief, Patent Branch, Office of the Counsel, U. S. Atomic Energy Commission, Washington 25, D. C. Identify patents by number and title.

Portable Voltage Supply for Radiation Counters (2,628,338) C. D. Gould—high-voltage supply makes use of spring-powered generator adapted for manual operation.

Flow Valve Control (2,628,638) N. S. Herod, L. R. O'Neill—capable of minute adjustment by frictional plate clutch arranged between relatively coarsely adjustable and finely adjustable operating means. Useful in handling corrosive gases moving at low velocity.

Apparatus for Fractional Sublimation (2,628,892) A. F. Reid—useful for separating components of volatile solid mixture by process involving countercurrent flow of a solid and its vapors. Hot zone for vaporizing mixture and cold zone for condensing vaporized material are established in a helical passage rotated about its axis.

Filter (2,629,459) R. P. Hammond, J. A. Leary—for removing particulate matter from gas stream saturated with vapor such as water vapor. Filter made of 0.004-in.-diameter glass fibers packed to density of 0.1–0.6 lb/ft^3.

Radioactive Resistor (2,629,837) J. M. Benade, E. E. Goodale, W. P. Jesse—does not exhibit self-induced or self-generated voltage when no external potential is applied to electrodes. Consists of radioactively ionized gas and an electric conductor in contact with one of two electrodes. Self-induced voltage of conductor is of opposite sign and equal magnitude to self-induced voltage of electrode.

Tachometer (2,630,529) E. R. Mann, R. G. Hester—mechanical-electronic type adapted to produce output voltage proportional to speed of rotating shaft over wide range of speed.

Mist Filter (2,630,878) D. L. Hopper, H. E. Griner—small size and large capacity. Readily constructed and operates with moderate pressure drop to remove particles such as oil mist from gases.

Process for the Preparation of Fluorocarbons (2,631,170) R. D. Fowler—covers step of reacting trifluoride, selected from group consisting of MnF_3 and CoF_3, with hydrocarbon vapor at 150–400° C until all hydrogen of hydrocarbon compound has been replaced by fluorine.

Method of Forming Coating Containing Uranium & Method of Isotopic Analysis (2,631,245) B. Cohen—method for forming thin, uniform, adherent coating by electrolytic deposition of substantially all uranium present in a prepared solution. Coating is useful in determining isotopic composition of uranium by neutron bombardment and fission-particle counting.

Remote Control Manipulator (2,632,574) R. C. Goertz—designed to be mounted through or over a protective wall. Useful in performing mechanical operations with vessels and equipment containing radioactive material. Straight-arm manipulator comprises horizontal tube having tongs or jaws attached to one end and manipulating handle attached to other end. Operator has freedom of motion in three dimensions.

Separation Process for Actinium (2,632,763) F. T. Hagemann—process for separating actinium from acidic aqueous solution of actinium and radium salts at *p*H of 2.5–4.5 by treating with a solution of fluorinated beta-diketone in non-polar water-immiscible solvent, and separating radium-containing aqueous phase from immiscible solvent containing actinium chelate. Actinium extracted with acidic aqueous solution of $pH < 2.5$. Process may be used to separate actinium and thorium by adjusting *p*H of acidic solutions.

Device for Separating Particles of Different Masses (2,633,539) W. Altar—particles such as isotopes separated by passing through two synchronized alternating electric fields separated by a field-free space, then through a decelerating chamber and a magnetic field to a collecting chamber.

Electrical Apparatus and Method (2,633,540) V. C. Wilson, J. A. Simpson—electrical field-reversing circuit, employed with radiation counter tube, speeds up collection of positive-ion cloud, thereby decreasing deadtime of counter tube to $<10^{-5}$.

Leakage Testing Method (2,633,740) J. P. Howe, A. B. Greninger, R. F. Plott—method for testing a jacketed body for airtightness, particularly the seam weld that seals jacket portions.

High-Frequency Shunt (2,634,307) Q. A. Kerns—shunt provides voltage signal independent of frequency variations by isolating connected meter from inductive voltages produced in shunt.

Pocket Radiation Meter (2,634,374) F. R. Shonka—adjustable electrometer employing preformed scale, in combination with charging switch providing gas-tight seal, permits mass production of pocket dosimeter.

Preparation of Uranium Bromide (2,635,035) J. E. Powell—uranium tetrabromide prepared by reacting uranium nitride with bromine at 450° C or above.

Preparation of Zirconium Tetrafluoride (2,635,037) H. A. Wilhelm, K. A. Walsh—method for production of anhydrous zirconium tetrafluoride may be successfully used to prepare zirconium metal. Aqueous solution of zirconium oxychloride treated with aqueous hydrofluoric acid to form zirconium fluoride precipitate which is dried at 100–110° C and then heat treated for several hours at up to 575° C in presence of dry HF.

Method and Apparatus for Stereoscopic Recomposing and Measuring (2,635,339) W. M. Powell, H. P. Hernandez, Jr.—useful for recording, under a given set of optical conditions, of full-size visual image of path of particle in space, and the recomposing in full size of the image under identical set of optical conditions.

Production of Granular Beryllium Fluoride (2,635,944) K. A. Walsh, H. A. Wilhelm—by contacting thin bed of beryllium hydroxide with anhydrous hydrogen fluoride for several hours at 300–350° C.

Preparation of Powdered Thorium (2,635,956) H. A. Wilhelm, P. Chiotti—massive metal converted to ThH_2 by treatment with hydrogen at 600–650° C and then to ThH_{3-4} by lowering slowly to 100° C. Introduction of hydrogen is discontinued, furnace evacuated, and temperature raised to 700° C, thus producing powdered metal.

Rare Earth Separation by Anion Exchange (2,636,044) E. H. Huffman, R. L. Oswalt—rare-earth-citrate complexes adsorbed from acidic aqueous citrate solution on strong base-type anion exchange resin and selectively eluting complexes in order of increasing

rare-earth atomic number with citric acid solution (*p*H of 1.5–3.0).

Pulse Equalizer (2,636,118) B. Smaller—for measuring coincidences of electrical pulses by transforming pulses of random amplitudes into pulses of equal amplitude in which delay time for all pulses is constant.

Uranium Complexes of Heterocyclic Diketones (2,636,886) H. I. Schlesinger, H. C. Brown—preparation of tetravalent and hexavalent uranium complexes with heterocyclic beta diketones such as furane, thiophene, pyrrole, and coumarone.

Ion Source Unit (2,636,990) J. D. Gow, J. S. Foster—employs magnetic field to influence electron discharge and utilizes arrangement for removal of ions from center of ion density.

Fast Counting Circuit (2,636,993) M. J. Jakobson—high-speed electronic counter has double-coincidence circuits for identifying pulses in presence of high background noise. Employs pair of photomultiplier tubes, each attached to scintillation crystal aligned in path of particle beam.

Apparatus for Attaching Filaments to Electrodes in Machines for Coating with Metal Vapors (2,637,297) Z. M. Shapiro—particularly useful in hot-wire method of preparing metals, such as zirconium, by thermal decomposition of volatile halide.

Apparatus for Attaching Filaments to Electrodes in Machines for Coating with Metal Vapors (2,637,298) Z. M. Shapiro—electrode-tip assembly for attachment of hot-wire filament to electrode employs easily assembled and disassembled and inexpensive current-carrying elements.

Method of Dispersing Materials in Water (2,637,536) J. De Ment—comprises introducing mixture of solid carbon dioxide and material to be dispersed into liquid.

Vacuum Die-Casting (2,637,882) R. F. Plott—evacuable-type die-casting machine maintains vacuum-tight seal without applying pressure by either die section. Seal remains relatively cool.

Production of Uranium Tetrafluoride (2,638,406) A. D. Tevebaugh, F. Vaslow—by contacting uranium hexafluoride at moderately elevated temperature with HCl, HBr, or HI.

Improved Window for Alpha Particle Counters (2,638,560) C. J. Borkowski—evacuable-type counting chamber employs thin nylon-foil window which is transparent to alpha particles and soft betas and sufficiently robust to withstand an appreciable pressure differential.

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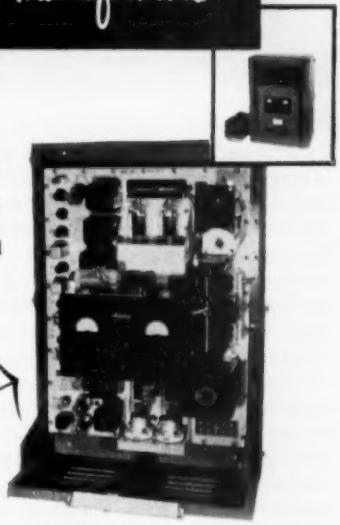

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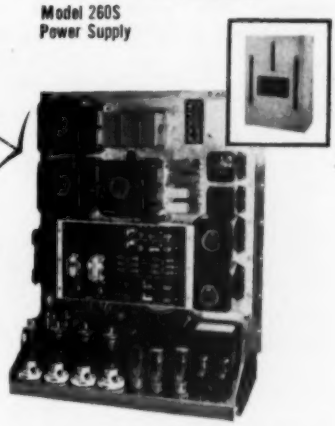

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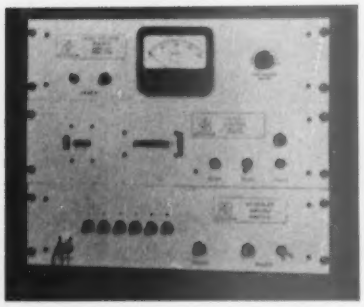
PRODUCTS AND MATERIALS

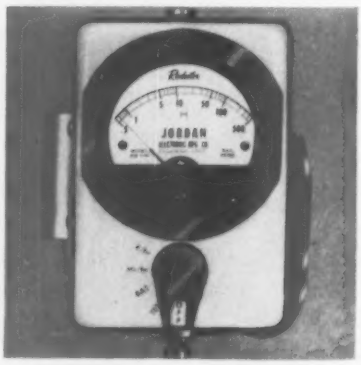


Binary Scaler

Detectolab, Inc., 6544 Sheridan Rd., Chicago 26, Ill. The model DS1 binary scaler is made up of the model DS2 scaling unit, model DV1 regulated high-voltage supply, and model DZ5 scaler-control panel. Scale-of-64 DS2 has resolving time <2 μsec, adjustable input sensitivity set at 250 mv, and self-contained plate supply. Connectors are provided for preamplifier or scintillation-counter input and positive or negative pulse output. DV1 supply provides 500–2,000 volts, continuously variable, with $<1\%$ variation in output voltage for 10% change in line voltage. DZ5 panel controls any number of scaling units operating in tandem. Timer reads up to 999.99 ± 0.01 min; register is 6-digit Veeder-Root. DA3 pulse amplifier, illustrated, has gain of 1,000, rise time <0.5 μsec, decay time <3.5 μsec, 4-mv input sensitivity, 10-volt-amplitude output. (P-1)

Radioactivity Analysis Kit

Landsverk Electrometer Co., 550 W. Garfield Ave., Glendale 4, Calif. The model L-75KA analysis kit is said to have a limit of sensitivity 300–3,000 times lower than 10-day and 30-day fission-product contamination limits set by the Federal Civil Defense Administration. The kit contains an analysis unit (NU, Aug., '50, p. 96), battery-operated light source, polystyrene and aluminum dishes for liquid and dry-ashed samples, copper planchets and planchet holders, 3 aluminum filters, and handbook of instructions. These are contained in a plastic-lined case. Handbook contains filter-transmission curves for fission-product beta rays from the first to tenth day after nuclear event. (P-2)



Portable Monitor

Jordan Electronic Mfg. Co., Inc., 119 E. Union St., Pasadena, Calif. The Radector, a portable gamma-radiation detector, is an ionization-chamber monitor available in two models. Model AG-50 has ranges 0.05–50 mr/hr and 0.05–50 r/hr; model AG-500 measures 0.5–500 mr/hr and 0.5–500 r/hr. Accuracy is $<\pm 15\%$ of radiation intensity. The battery-powered unit operates by a single control; battery life is 350 hr of continuous use or 1–2 yr intermittent use. (P-3)

Beta-Ray Sources

Technical Operations, Inc., 6 Schouler Court, Arlington 74, Mass. Beta-ray sources, hermetically sealed in stainless steel with a 0.004-in. window, contain a uniform distribution of strontium-90 activity. Strengths between 5 and 100 mc, or more, may be specified. Suggested uses are in medical applicators, thickness gages, and calibration of high-range survey meters. (P-4)

Decimal Scaler

Beckman Instruments, Inc., Berkeley Scientific Div., 2200 Wright Ave., Richmond, Calif. The model 2105 decimal scaler can be used for Geiger or scintillation counting. A selection of preset counts and scaling factors is provided for operation of an external register, printing device, or counting-rate computer. The unit is direct reading; it utilizes two plug-in decimal counting units and a four-digit mechanical register. High voltage is 300–2,500 volts. Standard ¼-volt input sensitivity is provided. (P-5)

Wirewound Resistors

Shallcross Mfg. Co., Collingdale, Pa. The type G resistors are claimed to utilize the heat-resistant properties of fiberglass insulated wire to increase wattage ratings 5 to 10 times over standard wirewounds of the same dimensions. The resistors are rated for a 150° C temperature rise above an ambient of 25° C. They are available in standard bobbin sizes with wattage ratings from 1 to 20 watts. (P-6)

Counting-Rate Meter

Utting Associates, Inc., 290 Centre St., Newton 58, Mass. The RM-1A ratemeter is designed for use with moving-coil or potentiometer-type recorders or almost any scaler. It is direct reading

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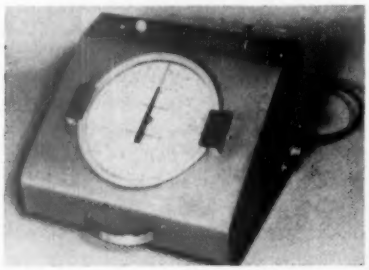
with full-scale ranges of 300, 1,000, 3,000, 10,000, 30,000, and 100,000 cpm. A choice of time constants permits selection of 1%, 3%, or 10% of full-scale probable error on any range. Coincidence loss is said to be <2%, full scale, on 100,000-cpm range and negligible on other ranges; precision is better than 1%. Input requirements are positive or negative pulses, >5-volt amplitude. Recorder output is 50 volts ±10% full scale at load current up to 5 ma. (P-7)

Binary Scaler

Nuclear Instrument and Chemical Corp., 229 W. Erie St., Chicago 10, Ill. The model 182 is available with 500–5,000 or 500–2,500 volt variable power supply, with electrically reset timer and register, or manual-reset register with no timer. Instrument has Higinbotham scale-of-256 with 8-position scale-selection switch. Linear amplification is 1 mv to 1 volt; resolution time, 2 μsec; and amplifier risetime, <0.2 μsec. (P-8)



Counting-Rate Computer

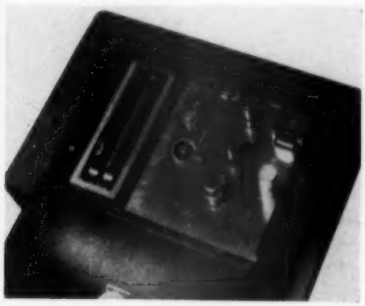
Radioactive Products, Inc., 443 W. Congress, Detroit 26, Mich. The model C-11 counting-rate computer provides a direct reading of average counting rate with any scaler. It has 5 automatic preset count ranges; a count-stop-clear lever controls both scaler and computer. At conclusion of counting, a dial pointer gives the counting-rate reading directly. (P-9)

Radiation Detector

Consolidated Engineering Corp., 300 N. Sierra Madre Villa, Pasadena 8, Calif. The Gamatek radiation detector, basically a moving-vane electrometer, indicates accumulated dosage of γ- and X-rays on a direct-reading dial. By observing the time the needle takes to cross dial, it may also be used as a radiation ratemeter. Full-scale reading is 250 mr. Instrument is zeroed by an integral friction charger operated through an external knob. No batteries are required. (P-10)

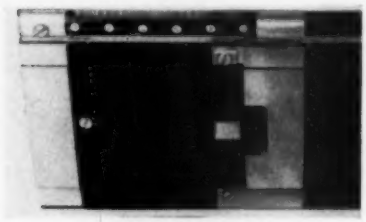
Two-Speed Chart Drive

Minneapolis-Honeywell Regulator Co., Industrial Div., Wayne & Windrim Aves., Philadelphia 44, Pa. This two-speed chart drive automatically boosts chart speed 30 or 60 times (depending on model) when the process varies beyond preset limits. When normal conditions return, chart speed drops to its usual pace. It is designed for single-record strip-chart instruments and for conversion of single-speed instruments. Speed changes may be made with a manual switch. (P-11)



Frequency Standards

Central Scientific Co., 1700 Irving Park Rd., Chicago 13, Ill. These frequency standards are made as 60- or 100-cycle-output models; other frequencies are available. Temperature range is −20 to +75° C with 1 or 5 ppm/° C temperature coefficient; tuning accuracy is ±0.003%. Line-frequency variations are said to have no effect on output. Standards are rated at 40 volts, a-c, with 2, 5, 10, 25, or 50 watt output. (P-12)



Data-Reduction Scale

Gerber Scientific Instrument Co., 162 State St., Hartford 3, Conn. The GraphAnalogue reads directly linear and arbitrary nonlinear functions in such cases as obtaining infrared curve ratios, normalizing mass spectrometer curves, analyzing diffraction patterns, and reading oscillographs directly. The scale operates with two springs, one having 100 coils calibrated in fives and tens, and the other carrying the numbers 0, 2, 4, 6, 8, and 10. Both springs are attached to a slide that extends them the desired length; the slide is self-locking in any position and carries a hairline with it. (P-13)

Self-Luminescent Sources

Tracerlab, Inc., 130 High St., Boston 10, Mass. Tritium-activated self-luminescent materials serve as light sources providing luminosity up to 25 microlamberts. Two types of sources are available: tritium-labeled organic phosphors and a tritiated solid mixed with a phosphor such as zinc sulfide. Organic phosphors have spectral emission characteristics of the molecule; peak spectrum is at 3,800 Å with some emission in visible region. Mixed type can

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be prepared with maximum peak from 4,000 to 7,000 Å, depending on phosphor. Tritium decay corresponds to loss in light output of 5%/yr. (P-14)

Planchet Counting Shield

Nuclear Research and Development, Inc., 6425 Etzel Ave., St. Louis 14, Mo. The model LH-3 shield, for scintillation counting of samples in planchets, surrounds counter and sample with 1½ in. of lead. Planchets up to 2-in. diameter and ¼-in. deep may be used. Recesses, 2⅜-in. diameter and ⅛-in. deep, permit mounting absorbers over planchets. Clamp, for adjusting counter height up to 8 in., is bored to order to accommodate counter diameter between 2⅜ and 2⅝ in. (P-15)

Spectrometer

Varian Associates, 941 Varian St., San Carlos, Calif. The model 4300 high-resolution spectrometer, principally applicable to compounds containing hydrogen or fluorine, detects differences in nuclear magnetic resonance structural spectra of isomers. Comparison of resulting oscilloscope traces against those obtained from known fluorine compounds makes it possible to identify structure in the two isomers. Addition or substitution of available radiofrequency units permits studies of many other isotopes. In operation, spectra are observed and recorded by strip chart or oscillograph. (P-16)

Beta-Gamma Counter Tube

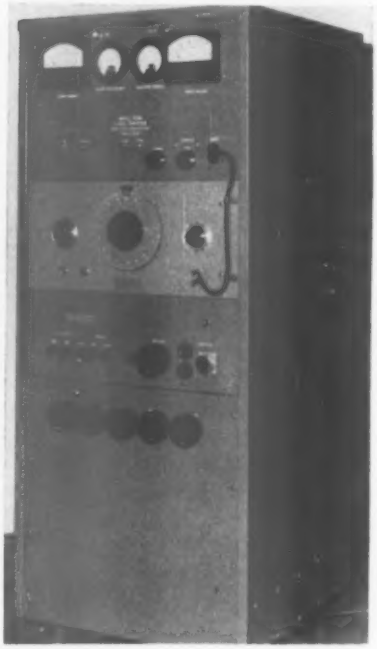
Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio. This improved version of the 1B85 beta-gamma counter tube has wall strength increased by five times against over-all pressure and by 2½ times against point pressure. Sizeable dents in the 30-mg/cm² aluminum side wall are said not to affect operation, except to shorten plateau. The tube has a 200-volt plateau with maximum 5%/100-volt slope, operating voltage 900 volts, threshold voltage 800 volts, and life of 10^9 counts. (P-17)

Potentiometer

Electro-Mec Laboratory, 19 Murray St., New York 7, N. Y. The type 1418 potentiometer is a voltage-dividing resistor with shaft torque as low as 0.025 oz-in. Resistance values are available between 100 and 350,000 ohms. Rated at 3 watts, the potentiometers provide electrical rotation up to 360 deg, linearity to 0.1%, and resolution down to 0.03%. The toroidally wound resistor element is 3¾ in. long. (P-18)

Radioactivity Battery

Radiation Research Corp., Box 8126, W. Palm Beach, Fla. The model E-50 radioactivity battery has an open-circuit voltage of 10 kv, maximum; no-load current is about 50 μμa, calibrated to ±1%; and capacity is <4 μμf. Charging rate is 10 volts/sec, open circuit, linear to 100 volts. Ionization source is 10 mc of Sr^{90} (25-yr half-life). External radiation 1 in. from surface is less than permissible tolerance for a 40-hr week. Operating temperature is −65 to 65° C. Suggested uses are: dosimeter charger, calibrator for electrometers, bias high-resistance circuit elements, and test insulation. (P-19)



Power Amplifier

John Fluke Engineering Co., 1111 W. Nickerson St., Seattle 99, Wash. The model 200A a-c power amplifier furnishes 0–115 volts over the range 40–4,000 cps. It is rated at 1,000 watts at 75% power factor with distortion of not more than 1½% at unity power factor, and not more than 3% at 75% power factor. Regulation at unity power factor is 7%; output voltage is substantially unaffected for ±10% line-voltage change. (P-20)

Regulated Power Supply

Kepco Laboratories, 131-38 Sanford Ave., Flushing 55, N. Y. The model 1520 power supply is continuously variable from 0 to 1,500 volts and delivers 0–200 ma. In the range 30–1,500 volts, output voltage variation is <½% for line fluctuation of 105–125 volts and load variation from minimum to maximum current. Ripple is <30 mv peak to peak. (P-21)

Want more information? Use post card on last page.

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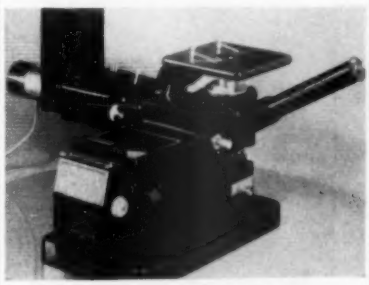
Analog Computer

North American Philips Co., Inc., Research & Control Instruments Div., 750 S. Fulton Ave., Mount Vernon, N. Y. This counting-rate computer is designed to record random counting rates on a linear chart with a constant computed statistical accuracy. The computer makes use of Ohm's Law as the analog to the basic counting equation, $nT = N$, where n = counting rate, T = time interval, and N = total number of counts. Computer must be used with a scaling circuit adjusted for fixed-count operation; range is controlled by choice of scale factor and speed with which computer slidewire is driven. (P-22)

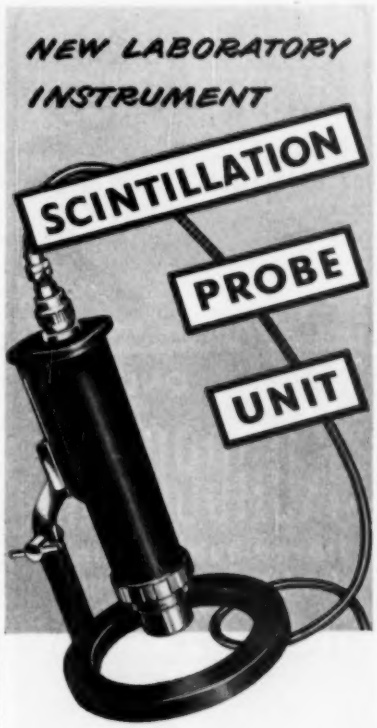
Slide-Wire Potentiometer

G. M. Giannini & Co., Inc., 117 E. Colorado St., Box N, Pasadena 1, Calif. The model 85171A slide-wire multiturn potentiometer is available in grades of ±0.05% and ±0.25% linearity and rotational tolerances of +1, −0 deg. Characteristics are said to include infinite resolution, extremely low operating noise level, low starting torque of 0.6 oz-in., minimum inertia effects, and life of 1,000,000 cycles. Resistances of 2 ohms per turn and 50–250 ohms per turn are available in 1–10 turn potentiometers. (P-23)



Microscope-Metallograph

Opplem Co., Inc., 352 Fourth Ave., New York 10, N. Y. The Galileo CSF metallurgical microscope and metallograph is said to occupy only $\frac{1}{10}$ to $\frac{1}{20}$ the space normally taken by such instruments. Magnification with visual observation is up to 1,000×, and



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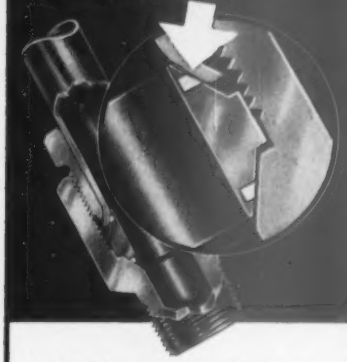

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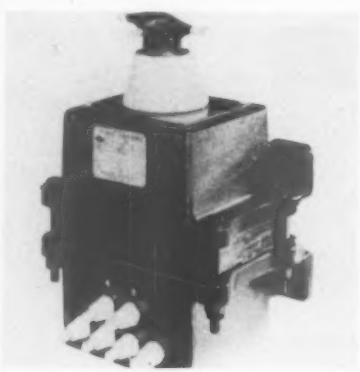
with photographic and projection observation up to 1,500×. Two dry objectives are provided for low and medium magnifications and one oil-immersion objective for high magnifications. Seven photographic lenses cover the full magnification range. An opaque illuminator allows bright-field and dark-field observation. (P-24)

Potentiometer

Trans-Sonics, Inc., Bedford Airport, Bedford, Mass. The type 71-5 pressure-operated potentiometer, for the range 0–15 psia, has the potentiometer winding and mechanism hermetically sealed in a vacuum. The potentiometer can be used on liquid or gas systems since the pressure medium does not contact the winding. Accuracy is ±2% of full scale; resistance of winding is 7,500 ohms; maximum applied voltage on winding is 75 volts, d-c or a-c rms, continuous. (P-25)

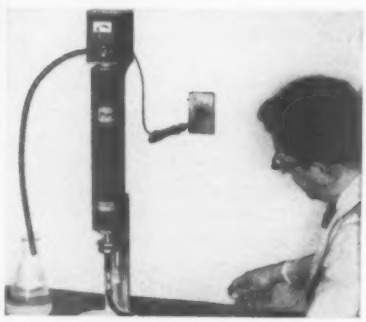


Filament Transformer

Magnatran, Inc., 246 Schuyler Ave., Kearny 1, N. J. This air-cooled transformer is designed especially for supplying filament voltages to rectifier tubes. Primary taps are provided at 200, 210, 220, 230, and 240 volts, or for any series of taps desired. Either 50- or 60-cycle input may be used. The unit is filled with a compound that transfers heat from coils to case and excludes dust and moisture. (P-26)

Power Supplies

Atomic Center for Instruments & Equipment, Inc., 489 Fifth Ave., New York 17, N. Y. Beva models 300 and 301 power supplies have outputs of 500–1,600 and 1,000–5,100 volts, d-c, respectively. Maximum output for both instruments is 1 ma. Regulation is 0.01% for load variation from zero to 1 ma and line-voltage change from 105 to 130 volts. Voltage variation is <0.1%/day. Noise and ripple is ±0.020 volts at 5 kv. Models are positive or negative grounded. (P-27)



Water Demineralizer

Penfield Mfg. Co., Inc., 19 High School Ave., Meriden, Conn. The 1953 model permanent cartridge demineralizer utilizes a sight indicator for adjusting intake flow to the optimum rate for most efficient ion-exchange action. It supplies 10 gal/hr of purified water. With raw water containing 5 grains of solids, one resin charge furnishes 200–230 gal of water. An electric purity meter provides continuous conductivity information, warning when the resin charge needs replacing. (P-28)

Servo Amplifier

Industrial Control Co., Wyandanch, N. Y. The 434-B transistor-magnetic servo amplifier is completely self contained, requiring no power supply or damping tachometer. It has six connections: 2 synchro inputs, 2 motor-control-phase outputs, and 2 for 117 volts 400 cycles. Single-speed autosyns are the recommended data

system, with voltage gradients between 0.25 and 1.0 volts/deg, at carrier-phase shifts between zero and 15 deg leading. Gain is adjustable and servo performance can be peaked to mate with wide range of gear ratios. (P-29)

Inverter

Ballantine Laboratories, Inc., Boonton, N. J. The model 700 inverter, in combination with a 60-cps voltage-sensitive device, measures d-c potentials down to 10 μv and detects d-c potentials down to 1 μv. Inversion ratios (d-c to a-c, rms) are 1:100 with input resistance of 10 megohms and 10:1 with 50 megohms. Inversion is directly portional to d-c magnitude and phase-sensitive to d-c polarity. (P-30)

All-Purpose Filters

Titeflex, Inc., 500 Frelinghuysen Ave., Newark 5, N. J. These filters are claimed to be usable for almost every filtration purpose. Standard models have capacities of 300–10,000 gal/hr of water; larger filters can be built to customers' requirements. Essential components of the filters are filter chamber, precoat tank, motor, and pump. Suspended particles down to $\frac{1}{10}$ micron are removed without affecting taste, smell, color or chemical composition. (P-31)

Electronic Pyrometer Controllers

Bristol Co., Waterbury 20, Conn. The Free-Vane electronic pyrometer controllers actuate relays, electric contactors, solenoid valves, and motor valves. Basic model provides low-open, high-open, and low-high control; an additional plug-in unit makes possible proportional current input for straight-line control of many heat-

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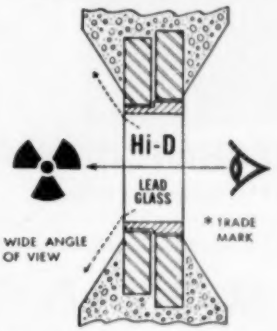

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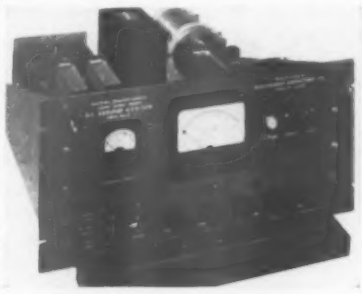
ing appliances. A double-control-unit model provides low-open-high or low-normal-high control. Controllers are made for ranges from 0–400° F to 0–3,000° F. (P-32)



D-C Amplifier

Measurement Engineering Ltd., Arnprior, Ontario, Canada. The AEP 1478 d-c amplifier measures currents in the range 10^{-13}–10^{-7} amperes. For continuous monitoring and automatic control of potential radiation health hazards, the amplifier operates alarm circuits at any current level in this range. Feedback is 100%; no-feedback gain is 1,200 or 250. Three switches are available for operating external control circuits; alarm level is continuously variable from 1.0 to 50 volts. Drift <50 mv/week. (P-33)

INDUSTRY NOTES

▶**Tracerlab, Inc., 130 High St., Boston 10, Mass.,** is building a 15,400-sq-ft building in Richmond, Calif., to replace the present Berkeley quarters of its Western Division. Completion is scheduled for November. The new structure will house scientific and administrative offices, radiochemistry laboratories, and facilities for nuclear instrument production and research.

▶**Servomechanisms, Inc.,** has moved its corporate offices from the Westbury Div., Westbury, N. Y., to 500 Franklin Ave., Garden City, N. Y.

▶**Atomic Instrument Co., Cambridge, Mass.,** is newly represented in the northern California area by Kittleson Co., 2166 Market St., San Francisco, Calif. H. F. Gray, Jr., is office manager.

▶**Nuclear Instrument & Chemical Corp., 229 W. Erie St., Chicago 10, Ill.,** offers a film-badge service similar to that being discontinued by ORNL. Interpretation is provided of γ-radiation from 150 kev to 20 Mev over the range 50 mr to 500 r. Film packets are supplied on a periodic basis. A

high-range catastrophe film is provided to measure accidental exposure to large amounts of activity.

▶**Consolidated Engineering Corp., Pasadena, Calif.,** has announced the promotion of three executives. Hugh F. Colvin, Robert L. Smallman, and Victor Pollock have been elected vice president and general manager, vice president in charge of sales, and treasurer, respectively.

▶**Westinghouse Electric Corp., 2519 Wilkens Ave., Baltimore 3, Md.,** is distributing the Siemens-Reiniger line of radiological equipment.

LITERATURE AVAILABLE

Control equipment maintenance. "Proper Maintenance of Control" contains trouble-shooting chart. *Allis-Chalmers Mfg. Co., 1316 S. 70th St., Milwaukee, Wis.* (L-1)

Metal hose. Catalog 200 includes charts on frictional losses vs flow rates in flexible hose, plus other engineering data. *Titeflex, Inc., 500 Frelinghuysen Ave., Newark 5, N. J.* (L-2)

Vacuum metallizing. Reprints of "Economical Finishing with Vacuum Metallurgy" discuss factors to be considered in applying process. *National Research Corp., 70 Memorial Dr., Cambridge, Mass.* (L-3)

Laboratory equipment. "What's New for the Laboratory," 18th ed., lists new items, including polyethylene aids. *Scientific Glass Apparatus Co., Inc., Bloomfield, N. J.* (L-4)

Pumps. "Cenco News Chats" includes articles on high-vacuum pumps, frequency standards, and oil diffusion pump. *Central Scientific Co., 1700 Irving Park Rd., Chicago 13, Ill.* (L-5)

Infrared absorption cells. Bulletin A-3 describes cells and accessories. *Perkin-Elmer Corp., Norwalk, Conn.* (L-6)

Laboratory appliances. Catalog describes Castaloy clamps, holders, and supports. *Fisher Scientific Co., 717 Forbes St., Pittsburgh 19, Pa.* (L-7)

Description of facilities. Pamphlet outlines engineering and production facilities and products of company. *Victoreen Instrument Co., 3800 Perkins Ave., Cleveland, Ohio.* (L-8)

Densitometer comparator. Bulletin 39 describes a densitometer that uses 2-beam optical null method. *Baird Associates, Inc., 33 University Rd., Cambridge 38, Mass.* (L-9)

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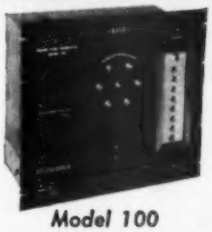

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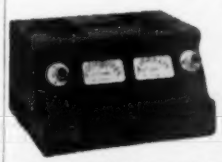

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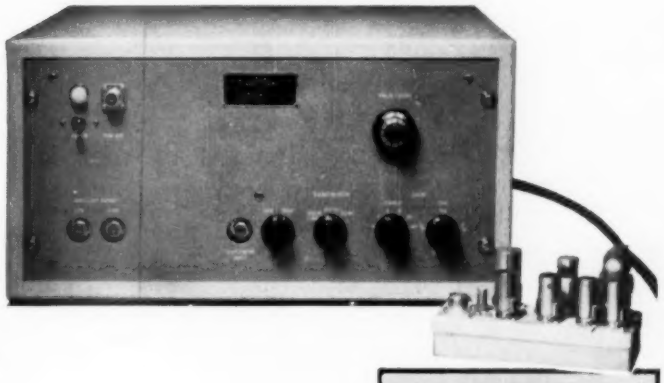

The new Linear Amplifiers, Models 217 and 218, are the latest versions of the ORNL A1 Amplifier. Both models have similar features except for an additional front panel receptacle in the Model 218 which allows signals to be fed directly into the output feedback loop, facilitating its use for pulse height analysis work.

Improved Features Include:

- more electrostatic shielding of amplifier and discriminator
- increased output linearity through use of twin triode as output cathode follower in amplifier
- separate transformer supplies filament voltage to preamplifier
- special transformers reduce high frequency transients — hermetically sealed transformers and chokes used throughout
- improved overloading characteristics
- large negative output pulse from discriminator
- pulse selector control by "Helipot" with "MICRODIAL"
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MODEL 219 LINEAR PREAMPLIFIER

For added gain when Models 217 and 218 are used with high impedance, low level input sources. High voltage can be supplied by connection through the 219 to scintillation or proportional detectors. A single receptacle provides signal, power and ground connection to the linear amplifier.

The Popular MODELS 204B and 204C

. . . evolved from the original A1 circuit, have broad acceptance by many laboratories and radio-activity research projects. They are widely used with ionization chambers, proportional counters, and in scintillation counting.

Both Models include:

Low impedance input circuit—accepts either positive or negative input signals—may be used with direct input or with Model 205B Preamplifier

Two outputs—low level to coaxial cable (maximum 5v @ 150 ohms), high level (maximum 100v without amplitude distortion)

Precision calibrated pulse amplitude discriminator. All pulses above selected level cause discriminator to give out +10v 0.4 microsecond pulses.

Gain control by coarse attenuator

Model 204B includes three-position "rise time" switch and a fine gain control. Model 204C includes input time constant control (0.6 to 16 microseconds) in seven steps; rise time control (0.2 to 2 microseconds) in five steps.

Full details and specifications on request. **Ask for Bulletin 218-1.**

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the Count-O-Matic *a new* nuclear *Scaler*

with the design features YOU specified!

HERE's a new automatic scaler, based on proven circuits in use for years in our previous instruments — yet incorporating the latest engineering advances. The features on this new Model 183 Count-O-Matic scaler are those which scientist-users told us they wanted most in a G-M scaler.

- **Binary (diode-coupled) scale of 256 with seven position scale selection switch for greatest reliability and use on samples over a wide range of activities.**
- **Coarse and fine high voltage adjustment gives pinpoint control over continuously variable range of 500-2500 volts.**
- **New 60-cycle test permits operational test or standby scaling action for reliable, longer life scaler operation.**
- **New high voltage standby reduces high voltage below operating level when high voltage is not needed. Voltage returns to previous level immediately when switch is turned to high voltage position.**
- **New built-in timer provides elapsed time indication for manual or predetermined count operation.**
- **New Count-O-Matic controls permit predetermined time operation with external timer.**
- **New one-button electrical reset zeros interpolation lights, register, and drum type timer.**
- **New sensitivity choices on input connector: 0.25 volt for G-M counting or 30 millivolts for scintillation counting.**
- **New auxiliary connector for remotely controlled operation by Model C-110 automatic sample changer and other accessories.**

Write for specification sheet or new 1953 catalog

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